

Original Article

Shear Bond Strength of a Resin Cement to Different Alloys Subjected to Various Surface Treatments

Fariba Ezoji¹✉, Kasra Tabari², Zahra Jaber Ansari³, Hassan Torabzadeh⁴, Mohammad Javad Kharrazi fard⁵

¹Assistant Professor, Dental Materials Research Center, Department of Operative Dentistry, Faculty of Dentistry, Babol University of Medical Sciences, Babol, Iran

²Assistant Professor, Department of Operative Dentistry, Faculty of Dentistry, Shahid Beheshti University of Medical Sciences, Tehran, Iran

³Professor, Department of Operative Dentistry, Faculty of Dentistry, Shahid Beheshti University of Medical Sciences, Tehran, Iran

⁴Associate Professor, Department of Operative Dentistry, Faculty of Dentistry, Shahid Beheshti University of Medical Sciences, Tehran, Iran

⁵Epidemiologist, Dental Research Center, Dentistry Research Institute, Tehran, Iran; Statistical and Methodology Department, School of Dentistry, Tehran University of Medical Sciences, Tehran, Iran

Abstract

Objectives: Micromechanical retention of resin cements to alloys is an important factor affecting the longevity of metal base restorations. This study aimed to compare the bond strength and etching pattern of a newly introduced experimental etchant gel namely Nano Met Etch with those of conventional surface treatment techniques for nickel-chrome (Ni-Cr) and high noble alloys.

Materials and Methods: A total of 120 discs (8×10×15 mm) were cast with Ni-Cr (n=20), high noble BegoStar (n=50) and gold coin alloys (n=50). Their Surfaces were ground with abrasive papers. Ni-Cr specimens received sandblasting and etching. High noble alloy specimens (BegoStar and gold coin) received sandblasting, sandblasting-alloy primer, etching, etch-alloy primer and alloy primer alone. Cylindrical specimens of Panavia were bonded to surfaces using Tygon tubes. Specimens were subjected to micro-shear bond strength testing after storing at 37°C for 24 hours.

Results: In gold coin group, the highest bond strength was achieved after sandblasting (25.82±1.37MPa, P<0.001) and etching+alloy primer (26.60 ± 5.47 MPa, P<0.01). The lowest bond strength belonged to sandblasting+alloy primer (17.79±2.96MPa, P<0.01). In BegoStar group, the highest bond strength was obtained in the sandblasted group (38.40±3.29MPa, P<0.001) while the lowest bond strength was detected in the sandblast+alloy primer group (15.38±2.92MPa, P<0.001). For the Ni-Cr alloy, bond strength in the etched group (20.79±2.01MPa) was higher than that in the sandblasted group (18.25±1.82MPa) (P<0.01).

Conclusions: For the Ni-Cr alloy, etching was more efficient than sandblasting but for the high noble alloys, higher Au content increased the efficacy of etching.

Keywords: Alloy Primer; Shear Strength; Resin Cements

Journal of Dentistry, Tehran University of Medical Sciences, Tehran, Iran (2016; Vol. 13, No. 1)

✉ Corresponding author:

F. Ezoji, Dental Materials Research Center, Department of Operative Dentistry, Faculty of Dentistry, Babol University of Medical Sciences, Babol, Iran

f_ezoji@yahoo.com

Received: 13 July 2015

Accepted: 22 November 2015

INTRODUCTION

Despite advancements in dentistry, achieving a strong bond between metal frameworks and resin cements through application of a simple effective technique is still a priority. Noble, high noble and base metal alloys have numerous applications in dental treatments i.e. dental bridges, porcelain fused to metal (PFM) crowns, post and core treatments, inlays and onlays. Resin-bonded fixed partial denture (FPD) is a conservative treatment in partially edentulous patients [1]. In restorations with metal frameworks, retention is achieved through micromechanical, macro-

mechanical and chemical methods. Studies have demonstrated that micromechanical retainers provide more retention than macro-mechanical ones [2]. Researchers have demonstrated that accumulation of stresses due to mastication at the interface of tooth-restoration or cement-substrate is responsible for the degradation of cement and debonding [3]. Defective bonding of resin cement to metal alloys increases the marginal gap, compromises bond strength and causes discoloration affecting both esthetics and retention of restorations [4]. Failure in alloy-cement interface is a multifactorial phenomenon.

Table 1: The composition of resin cement, etchant and metal alloys used in this study

Material name	Manufacturer	Composition	Lot N
Alloy primer	Kuraray Medical Inc., Japan	Acetone, 10MDP, 6VBATDT	408AD
Panavia F2.0 resin cement	Kuraray Medical Inc., Japan	Paste A: 10-MDP, silanized silica, hydrophobic aromatic and aliphatic dimethacrylate, hydrophilic dimethacrylate photoinitiator, dibenzoyl peroxide Paste B: Silanized barium glass, sodium fluoride, sodium aromatic sulfonate, dimethacrylate monomer, BPO	51223
Ni-Cr Alloy	Verabond II, Aalbadent, CA, USA	Ni 77.95%, Cr 12.60%, Mb 5%, Al2.90%, Co 0.45%, Be 1.95%	
High-Noble Alloy	BegoStar, Bego, Bremen Germany	AU 54%, Pd 26.5%, Ag 15.5%, Sn 2.4%, In 1.4%, Ru 0.1%, Re 0.1%	138180
Yellow Gold	Iran	Au, Cu	
Acid-Etch	Experimental, Iran	Nitric acid, chloridric acid, silica nano particles	Experimental

An important factor responsible is inadequate surface preparation of the metal framework [5]. Several micromechanical surface treatment methods have been introduced among which etchant gels have a simple application offering clinically acceptable results [6,7]. Furthermore, using etchant gel eliminates the need for an additional office visit and is inexpensive [8]. Also, in case of debonding, with this system the dentist can etch and bond the restoration again in the office without the need for sending it to a dental laboratory [9]. Considering the high retention obtained by application of micro-mechanical methods and easy application of etchant gels and their favorable efficacy compared to other micromechanical methods, in the current study we tested a newly introduced experimental etchant gel namely Nano Met Etch and compared it in terms of bond strength and etching pattern with the conventional surface treatment techniques for base-metal (Ni-Cr) and high noble (BegoStar and gold coin) alloys.

MATERIALS AND METHODS

This in-vitro experimental study was conducted on 20 discs made of Ni-Cr (Verabond II, Aalbadent, CA, USA) and 100 discs made of high noble alloys with different Au contents including 50 discs made of gold coin (Tehran, Iran) and fifty discs made of BegoStar (Bego, Bremen, Germany) alloys (10×15×0.8mm).

The composition of resin cement, etchant and metal alloys used in this study is summarized in Table 1.

Specimen Preparation

Ni-Cr group

Surface of specimens was ground with silicone carbide abrasive papers (240, 400, and 600 grit) (Soflex, Starcke's Co., Melle, Germany) for three minutes and then rinsed. The 20 Ni-Cr specimens were randomly divided into two subgroups of 10 each. The first subgroup was abraded with 50µ aluminum oxide (Al₂O₃) airborne particles (Ortho Technology Inc., FL, USA) at 60 PSI pressure for 10 seconds from a 10 mm distance using MicroEtcher sandblaster (Danville Materials Inc., CA, USA). Surface of the second subgroup specimens was covered with 1 mm thickness of Met Etch etchant and etched for 10 seconds. Conversion of the color of etchant from clear to dark green was indicative of a complete reaction. Specimens were rinsed for one minute under running water, cleaned in an ultrasonic bath (BioSonic, Uc300, Coltene/Whaledent Inc., OH, USA) containing 96% ethanol (Bidestan Co. Qazvin, Iran) for 10 minutes and air dried with air spray (2 bar pressure) for 10 seconds.

BegoStar alloy

In this group, 50 discs with the mentioned dimensions were waxed up and cast with high noble alloy (BegoStar, Bego, Bremen, Germany). Specimens were abraded with 240,

400, and 600 grit abrasive papers (Soflex, Starcke's Co., Melle, Germany) for three minutes under running tap water. Specimens were then rinsed with water and cleaned in an ultrasonic bath containing ethanol for 10 minutes and divided into five subgroups of 10 each. The first subgroup was sandblasted with 50 μ m aluminum oxide airborne particles at 60 PSI pressure from a 10 mm distance for 10 seconds, washed in an ultrasonic bath containing ethanol for 10 seconds and air-dried with air spray (2 bar pressure) for 10 seconds.

In the second subgroup, the specimens were abraded, washed and dried as done in the first subgroup and then their surfaces were coated with a layer of alloy primer (Kuraray Medical Inc., Tokyo, Japan) using a microbrush and were given time according to the manufacturer's instructions for the setting to occur. The third subgroup was etched with Nano Met Etch for five minutes according to the manufacturer's instructions and until the gel color changed to brown. The thickness of etchant on the surface of specimens was one millimeter. Specimens were then rinsed under running water for one minute and cleaned in an ultrasonic bath and dried as described above. In the fourth subgroup, surface of specimens was coated with one layer of alloy primer (Kuraray Medical Inc., Tokyo, Japan) using a microbrush and allowed time for the setting to complete according to the manufacturer's instructions. In the fifth subgroup, surface of specimens was first etched with Nano Met Etch for five minutes and until the gel color changed to brown. The thickness of etchant on the surface of specimens was one millimeter. Specimens were then rinsed under running water for one minute, cleaned in an ultrasonic bath and dried as described above. Surface of specimens was then coated with one layer of alloy primer (Kuraray Medical Inc., Tokyo, Japan) using a microbrush and allowed time for the setting to complete according to the manufacturer's instructions.

Gold coin group

In the third group, 50 discs were waxed up and cast with gold coin (21.5 carat gold) alloy. Specimens were abraded under running water using 240, 400 and 600 grit abrasive papers, rinsed and cleaned in an ultrasonic bath containing ethanol for 10 minutes and dried as in previous groups. Specimens were divided into five groups of 10 specimens each, which were treated similar to the above-mentioned five subgroups.

Bond strength measurement

Panavia F 2.0 resin cement (Kuraray Medical Inc., Tokyo, Japan) was bonded to the prepared surfaces using Tygon tubes (Tygon, Norton Performance Plastic Co., Cleveland, OH, USA) with an internal diameter of 0.7 mm and height of 1 mm. Specimens were light cured with Demetron light curing unit (Demetron LC, Kerr, Orange, CA, USA) for 40 seconds and then stored in an incubator (Peco PI-455G, Pooya electrics, Tehran, Iran) at 37°C for 24 hours. After completion of this time period, Tygon tubes were cut by a scalpel and removed. Discs with resin cement cylinders were fixed to the microtensile tester (Bisco Inc., CA, USA) with cyanoacrylate glue to measure bond strength. A thin wire with 0.25 mm cross-section was formed as a loop. The loop was connected to the base of resin cement cylinder at one end and to the metal rod of the bond strength tester at the other end. Micro-shear forces were applied at a crosshead speed of 0.5 mm/min until failure occurred [10]. The force at which resin cement cylinder was detached from the surface of alloy was recorded as failure load (N) for the respective specimen. The shear bond strength was calculated by dividing the failure load by the bonding area and was recorded in MPa.

Determining the mode of failure

Specimens in all three groups were evaluated under a stereomicroscope (Model SZ-PT; Olympus, PA, USA) at $\times 30$ magnification after failure. In general, three modes of failure exist:

adhesive (failure at the interface of resin cement and alloy), cohesive (failure within the alloy or the resin cement material) and mixed (both adhesive and cohesive).

In order to determine the mode of failure, the bonding area was divided into four sections and the mode of failure was determined in each section. According to Renata et al, [11] if the failure is of adhesive or cohesive type in three or more areas, the overall mode of failure would be the same as such. If two areas were adhesive and the remaining two were cohesive, the mode of failure would be determined as “mixed”.

Determining the etching pattern

In order to determine the pattern of etching in treated specimens, three discs in each group (a total of nine) were waxed up and cast. Surface of discs was abraded with 240, 400 and 600 grit (Soflex, Starcke's Co., Melle Germany) abrasive papers for three minutes under running water and cleaned in an ultrasonic bath containing ethanol and dried as mentioned earlier.

The first discs in the three groups at this step, the second ones after sandblasting with 50 μ m aluminum oxide particles from 1 cm distance and 60 PSI pressure for 10 seconds using a Micro-Etcher sandblaster (Danville Materials Inc., CA, USA) and the third discs after etching with Nano Met Etch were evaluated under a scanning electron microscope (SEM) (S4160, Hitachi, Tokyo, Japan) according to the manufacturer's instructions.

Statistical analysis

In order to evaluate the effects of materials and treatments, two-way ANOVA was applied. Since

the interaction effect was significant, the data were subjected to the subgroup analysis. To compare the micro-shear bond strength between the two subgroups of base metal alloys, the Student t-test was used.

One-way ANOVA and then the Tukey's HSD post hoc test were used to compare the effects of five surface treatments in each group of gold coin and BegoStar alloy. P values less than 0.05 were considered significant. All the statistical tests were applied using SPSS 16 for windows (SPSS Co., Chicago, IL, USA).

RESULTS

The interaction effect of the two independent variables on the micro-shear bond strength was significant ($P=0.01$); thus, the results were compared between subgroups using subgroup analysis as follows:

Effect of type of material

Analysis of the data with independent t-test demonstrated statistically significant differences in the mean bond strength values in relation to the type of material used ($P<0.00$); and there were significant differences in relation to the two types of surface treatments including etching and sandblasting ($P=0.00$) in the three alloys (Table 2).

As observed in Table 2, in the gold coin group, sandblasting caused a higher bond strength compared to etching ($P=0.033$). Similar result was obtained in the BegoStar group ($P=0.000$). However, in the Ni-Cr group, etching caused a higher bond strength compared to sandblasting (both P-values were 0.008).

Table 2: Bond strength of resin cement to the three alloys with two types of surface treatments (etching and sandblasting)

Material	Surface treatment	Mean	Standard deviation	P-value
Gold coin	Etching	22.3000	4.33026	0.033
	Sandblasting	25.8200	1.37744	
BegoStar	Etching	26.1500	6.22116	<0.001
	Sandblasting	38.4000	3.29005	
Ni-Cr	Etching	20.7900	2.01740	0.008
	Sandblasting	18.2500	1.82102	

Table 3: Multiple Comparisons between gold coin and BegoStar groups using independent sample t-test

Treatment	Material	Mean \pm SD	P-value (2-tailed)
Nano Met Etch	Gold Coin	22.3 \pm 4.33	0.126
	BegoStar	26.15 \pm 6.22	
Sandblasting	Gold Coin	25.8 \pm 1.37	<0.001
	BegoStar	38.40 \pm 3.29	
Sandblasting + alloy primer	Gold Coin	17.79 \pm 2.96	0.084
	BegoStar	15.38 \pm 2.92	
Etchant + alloy primer	Gold Coin	26.60 \pm 5.47	0.20
	BegoStar	29.96 \pm 5.86	
Alloy primer	Gold Coin	29.21 \pm 4.11	0.003
	BegoStar	16.59 \pm 2.54	

Effect of treatment

In order to compare the effects of various surface treatments in each group of gold coin and BegoStar alloy, one-way ANOVA and then post hoc test were employed, which showed significant differences among the five types of surface treatments in each group ($P < 0.001$ in both groups).

In the gold coin group, the lowest bond strength belonged to sandblasting + alloy primer while the highest was reported for sandblasting and etchant + alloy primer. In BegoStar group, the lowest bond strength belonged to sandblasting + alloy primer and also alloy primer alone subgroups ($P < 0.01$) while sandblasting caused the highest bond strength ($P < 0.001$).

For comparison of five types of surface

treatments in gold coin and BegoStar alloys, independent sample t-test was used, which found significant differences between sandblasting ($P = 0.00$) and alloy primer ($P = 0.003$) in this group (Table 3).

SEM findings

Comparison of Ni-Cr, gold coin and BegoStar alloys treated with Nano Met Etch demonstrated that numerous porosities and irregularities were present on the surface of specimens. Irregularities were significantly higher on the surface of Ni-Cr alloys (Figs. 1A and 1B). When the two high-noble alloys were compared (Figs. 2A, 2B and 3a) gold coin alloy had greater porosities and the surface of BegoStar alloy specimen was covered with crystalline deposits (Figs. 2A).

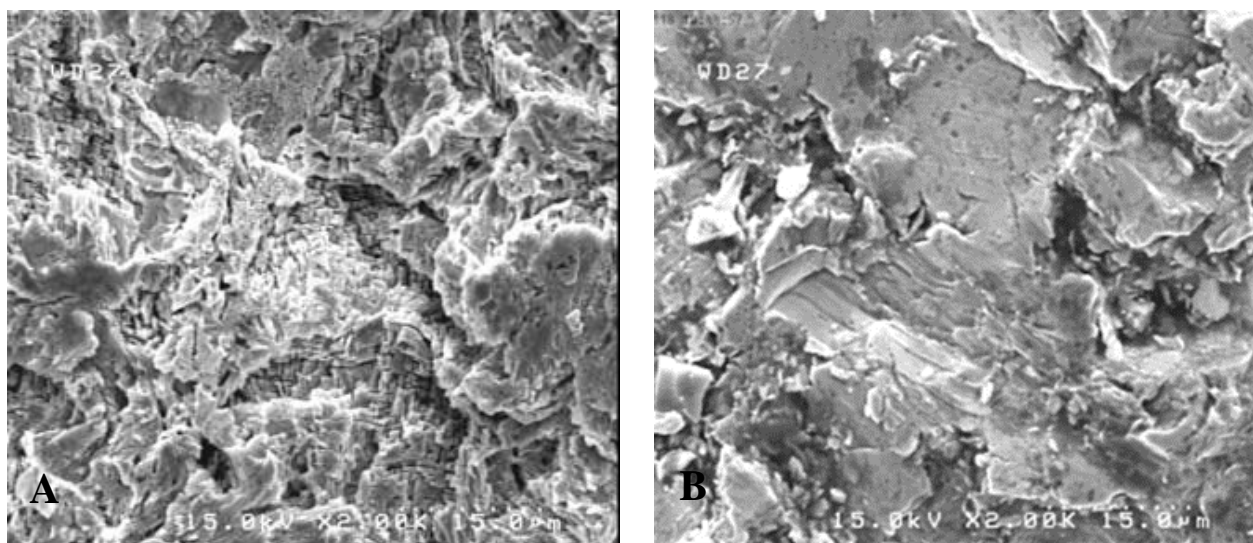


Fig.1: SEM micrograph of the Ni-Cr alloy ($\times 2000$); (A) etched surface, (B) sandblasted surface

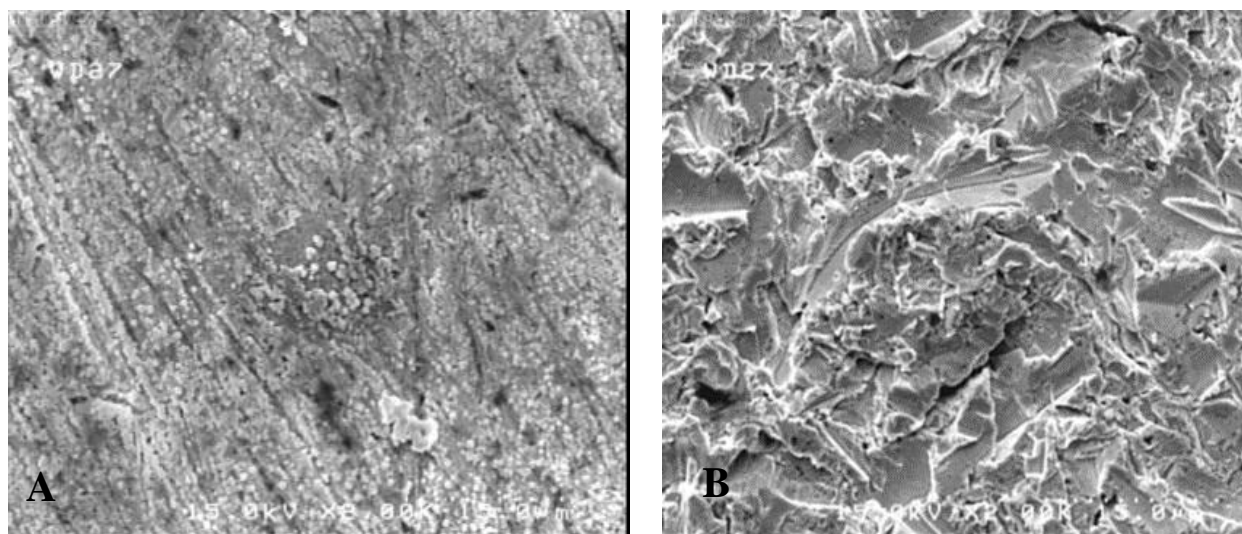


Fig. 2: SEM micrograph of the BegoStar alloy ($\times 2000$); (A) etched surface, (B) sandblasted surface

In the gold coin alloy, no obvious difference was found between the roughness of the sandblasted and etched surfaces (Figs. 3A and 3B). On the sandblasted surface of gold coin, there were compacted areas that were smooth and less porous (Fig. 3B).

SEM analysis of the sandblasted surface of the three alloys showed that the sandblasted surface of the BegoStar alloy was rougher than the sandblasted surface of the gold coin and the etched surface of BegoStar alloy (Figs. 2B, 3B and 2A).

SEM analysis also showed that the frequency of

irregularities was clearly greater in the etched surface of Ni-Cr alloy compared to the etched surface of BegoStar alloy (Figs. 1A and 2A).

Study of the mode of failure

No adhesive failure occurred ($n=0$) in the etched specimen of Ni-Cr alloy, sandblasted specimens of gold coin alloy, gold coin specimens treated with etchant + alloy primer and sandblasted BegoStar specimens. The highest number of adhesive failures occurred in sandblasted Ni-Cr alloy ($n=3$), sandblasted + alloy primer gold coin specimens ($n=4$) and sandblasted + alloy primer

Table 4: Failure mode in the three alloys

Metal	Surface Treatment	Failure Mode		
		Adhesive	Cohesive	Mixed
Ni-Cr	Etching	0	8	2
	Sandblasting	3	5	2
Gold Coin	Etching	1	7	2
	Sandblasting	0	7	3
	Etching + Alloy Primer	0	9	1
	Sandblasting + Alloy Primer	4	3	3
	Alloy Primer	2	6	2
	Etching	1	7	2
BegoStar Alloy	Sandblasting	0	9	1
	Etching + Alloy Primer	1	8	1
	Sandblasting + Alloy Primer	4	2	4
	Alloy Primer	3	3	4

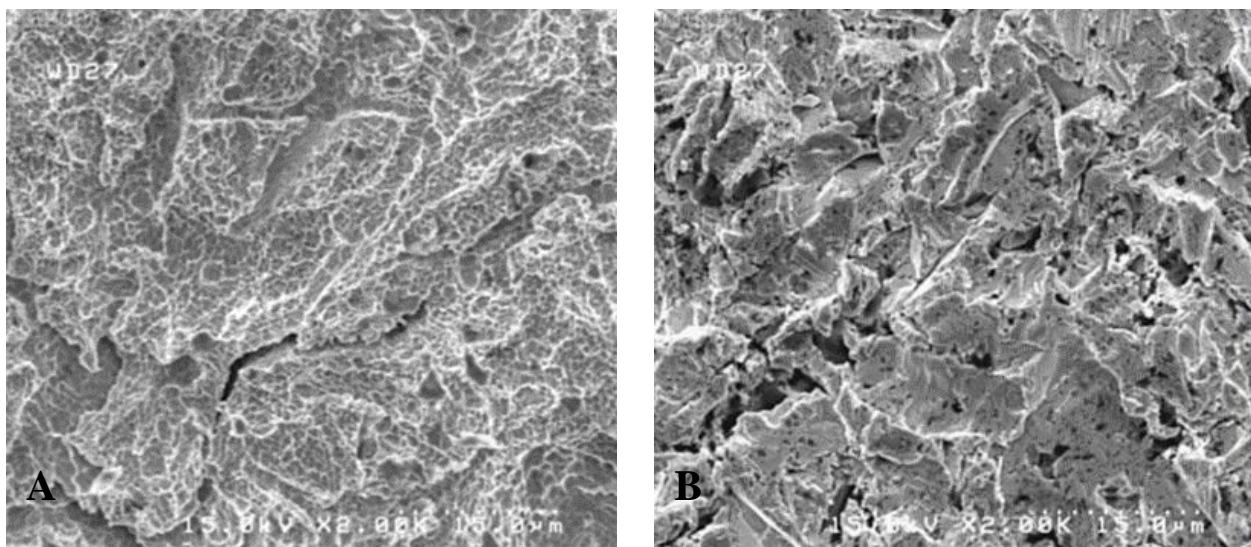


Fig. 3: SEM micrograph of the coin alloy ($\times 2000$); (A) etched surface, (B) sandblasted surface

BegoStar specimens ($n=4$). It should be noted that cohesive failure requires a higher amount of stress to occur compared to the mixed type. Number of cohesive failures is important for the assessment of the bond strength of groups with equal number of adhesive failures (Table 4).

DISCUSSION

In the Ni-Cr group, the bond strength in the Nano Met Etch subgroup was higher ($P<0.01$) than that in the sandblasted subgroup (Table 2), which may be due to the alloy composition and presence of beryllium because the Ni-Be phase is very susceptible to etching with Met Etch [12]. Conceição et al, [12] in 1994 found that bond strength of alloys containing beryllium was higher than that of alloys without it. Malek Nejad and Ghavam Nasiri in 2003 [13] and Isidor et al, [14] in 1991 reported similar bond strength in Ni-Cr alloy following sandblasting with $50\mu\text{m}$ alumina particles and chemical etching. Microscopically, Ni-Cr alloy has a dendritic structure. The alloy used in this study was a Ni-Cr alloy containing beryllium. In this type of alloy, inter-dendritic phase is a eutectic Ni-Be phase that is dissolved during acid etching and results in porosities [15]. On the other hand, base metals quickly form a superficial oxidized layer

at room temperature.

These superficial oxides play an important role in surface wettability and formation of a chemical bond with resin cement. Panavia resin cement also contains 10-MDP active monomer and forms a covalent bond with the oxide layer present at the surface of base metal alloys [16]. SEM micrographs of the Ni-Cr alloy revealed that in the pattern of etching by Nano Met Etch, rate of irregularities and surface porosities was greater than that in the sandblasted specimens. Consequently, the resin cement bond to the surface treated with Nano Met Etch was greater than that to the sandblasted surface (Figs. 1A and 1b). Another point worth noting is that overall porosities due to the understudy chemical etchant were more uniform than those due to sandblasting, which results in higher surface wettability in etched surfaces and lower wettability in sandblasted specimens. Other studies also confirm that acid etching causes a uniformly etched surface [17]. As observed, no adhesive failure occurred in the Ni-Cr alloys which means that the bond strength between the Nano Met etched surface of alloy and cement was higher than the cohesive strength of the resin cement; whereas, in the sandblasted specimens of this alloy three cases of adhesive failures (35% of

specimens) occurred (Table 4). The results of bond strength testing, SEM analysis and mode of failure were all in accord with one another indicating that in the Ni-Cr alloy, surface treatment with Nano Met Etch was significantly more effective than sandblasting. The gold coin alloy used in this study contained approximately 90% gold and 10% copper. The BegoStar alloy contained 54% gold and a combination of Au, Pd, Ag, Sn, In, Ru and Re. Based on the study results, the highest bond strength in the gold coin alloy group belonged to the sandblasted and etched-alloy primer subgroups while the highest bond strength in the high noble BegoStar alloy belonged to the sandblasted specimens. This finding is in accordance with that of other studies [18-20]. However, Dixon et al, [1] in 1994 stated that sandblasting of high noble alloys with 50 μ alumina particles yielded the lowest shear bond strength. Dixon et al, [16] attributed this finding to the different testing design. Vickers Hardness score of alumina particles used for sandblasting is higher than that of high noble alloys. Thus, they can easily scratch the alloy surface resulting in increased surface area and roughness. The gold content of gold coin alloy was higher than that of high noble BegoStar alloy and therefore, gold coin alloy has a lower hardness which is responsible for the higher porosity of sandblasted BegoStar specimens observed in SEM analysis (Fig. 2B). Gold coin alloy specimens showed lower porosity following sandblasting and their surface rather seemed compacted (Fig. 3B). Similar finding was reported for a high gold content alloy in another study [18]. Statistically, a significant difference was detected between the bond strength of BegoStar and gold coin alloy sandblasted specimens ($P=0.000$) and bond strength was higher in BegoStar sandblasted specimens (Table 3). Furthermore, no adhesive failure occurred in sandblasted BegoStar alloys but one adhesive failure occurred in gold coin alloy (Table 4). Number of cohesive failures was nine in BegoStar and six in gold coin alloys,

which is due to the difference in their bond strength (Table 4). Pairwise comparison of gold coin and BegoStar alloys treated with etchant revealed that the difference in bond strength between the mentioned two groups was not statistically significant ($P=0.126$). In other words, the efficacy of the understudy etchant was similar in the two alloys despite their different gold content. The pattern of etched surface and honeycombing observed on SEM micrographs of the gold coin alloy specimens was attributed to the fact that due to the high content of gold, the corrosion was severe and associated with destruction of walls resulting in development of shallower porosities (Fig. 3A). Reducing the etching time to decrease subsequent destruction of porosities may be further evaluated as a possible solution to this problem. Surface of etched BegoStar alloy specimens on SEM micrographs was not highly porous (Fig. 2A). Instead, crystalline deposits were observed covering the surface of specimens that may be the result of a reaction between acids present in the composition of etchant gel (nitric acid and hydrochloric acid) and elements in the composition of alloy especially Pd and Sn as well as the reaction of silica and palladium. Moderate bond strength in this group may be attributed to the formation of aforementioned crystals in the surface of specimens. However, Nano Met Etch contains nitric acid and considering the high solubility of gold in this acid, pores should be seen underneath these crystals due to the function of acid on the BegoStar alloy containing 54% gold. Finding a solution to prevent such occurrence may improve bond strength in this group. On the other hand, due to the composition of alloy primer, its application on the etched surface of gold coin alloy specimens increases the bond strength because of the formation of a chemical bond between VBATDT monomer and gold and copper atoms. In the current study, application of alloy primer similar to sandblasting resulted in the highest bond strength in

this group ($P=0.003$). Application of alloy primer yielded significantly different bond strength values in the two groups of gold coin and BegoStar alloys ($P=0.003$) and the bond strength following alloy primer surface treatment was higher in the gold coin group (Table 3). A possible explanation for this finding is the high affinity of thiol ($-SH_2$) and amine ($-NH$) groups present in 6-VBATDT monomer for gold and copper atoms because gold coin alloys have a higher gold content than BegoStar alloys and also contain 10% copper. Matsumura et al, [21] in 1999 reported a high bond strength following application of alloy primer due to the presence of 10-MDP and 6-VBATDT functional monomers in high noble alloys containing Cu. They explained this finding to be the result of high affinity of MDP monomer for Cu and VBATDT monomer for precious atoms.

Antoniadou et al, [22] in 2000 demonstrated that alloy primer significantly improved the bond strength of Panavia resin cement to high noble alloys. They concluded that this effect depended on the alloy composition and was greater in Au-Pt-Pd-In alloy than in Au-Ag-Cu-Pt alloy. This finding was in contrast to our study results because the BegoStar high noble alloy evaluated in our study was Au-Pt-Pd-In alloy. Abreu et al, [16] in 2009 also reported improved bond strength following the application of alloy primer on a high noble alloy. The lowest bond strength in BegoStar group in our study was reported in the alloy primer and sandblast + alloy primer groups ($P<0.01$), that can be explained by the low gold content and absence of Cu in alloy composition. In other words, the contradictory effect of alloy primer on the two high noble alloys in our study can be attributed to their different composition and mass percent of elements. Petrie et al, [5] in 2001 reported improved bond strength of Au-Pd alloy with sandblasting and alloy primer application. Barkmeier and Latta [23] in 2000 and Yoshida and Atsuta [24] in 1997 also mentioned improved

bond strength in noble alloys following sandblasting + alloy primer application. Parsa et al, [4] in 2003 noted a reduction in bond strength following sandblasting + alloy primer application in a high noble alloy, which is in accordance with our study result. Composition of the alloy used by Parsa et al, [4] was 52% Au, 26.9% Pd, 16% Ag, 2.5% In, 2% Sn, and 0.1% Ru, which is almost identical to the alloy used in our study. Abreu et al, [25] in 2007 found that application of alloy primer to the sandblasted surface of metal-ceramic copings cemented to minimally retentive preparations had no significant effect on improving the bond strength compared to sandblasting with 50μ alumina particles alone and only affected the location of debonding, which is in agreement with our findings. Fonseca et al, [10] in 2009 also reported higher bond strength of Panavia F to Ni-Cr alloy in sandblasted specimens compared to those treated with sandblasting + alloy primer. Such findings may be attributed to absence of a strong bond between alloy primer and sandblasted surface in high noble alloys or obstruction of surface porosities caused by sandblasting due to the copolymerization of alloy primer monomers. Silikas et al, [26] in their study in 2007 explained that 50% of sulfur groups in VBATDT monomer are converted to inactive sulfide on the surface of Au-Pd alloys, which significantly compromises the capacity of this primer to form a chemical bond with high noble alloys. However, it has been demonstrated that bond strength due to sandblasting significantly decreases following thermocycling [4,27]. Conduction of thermocycling in this study might have decreased the difference in bond strength of the two groups of sandblasting and alloy primer + sandblasting. Overall, in the gold coin group, application of alloy primer to the etched surface improved bond strength to the level of sandblasting (the highest); whereas, in the BegoStar group the primer did not significantly increase the bond strength of the etched surface. Application of alloy primer to the

sandblasted surfaces of BegoStar and gold coin alloys did not significantly change the bond strength and the lowest bond strength was reported in alloy specimens treated with sandblasting + alloy primer; while sandblasting alone yielded the highest bond strength in the mentioned two groups. This finding is in contrast to the claims of the alloy primer manufacturer since according to the manufacturer's instructions the alloy surface has to be sandblasted before the application of alloy primer. Different testing techniques or phases of the test may be responsible for this difference. Based on the study results, Nano Met Etch is recommended for use in alloys with a higher content of gold and lower content of Pd and Ag. In conclusion, since the minimum bond strength for optimal durability of bonded restorations is suggested to be 20 MPa, this study revealed that surface treatment of the three understudy alloys with Nano Met Etch was clinically efficacious. In order to generalize the results, these surface treatments have to be tested on high noble alloys with different compositions. The effects of storage in water and pH changes simulating the oral environment should also be evaluated. The impact of dynamic loading and the resultant fatigue on the durability of resin bond and also the effect of thermocycling on the bond strength have to be studied as well.

CONCLUSION

In Ni-Cr group, the efficacy of Nano Met Etch was higher than that of sandblasting.

In high noble gold coin alloy, Nano Met Etch + alloy primer and sandblasting were equally effective; however, sandblasting is recommended for high noble alloys with low gold content and high content of Pd and Ag (BegoStar).

In high noble alloys with a high Au content, Nano Met Etch surface treatment yielded more predictable results.

Application of alloy primer is not recommended for the sandblasted surfaces of high noble alloys

regardless of their composition.

REFERENCES

- 1- Dixon DL, Breeding LC, Hughie ML, Brown JS. Comparison of shear bond strengths of two resin luting systems for a base and a high noble metal alloy bonded to enamel. *J Prosthet Dent.* 1994 Nov;72(5): 457-61.
- 2- Dhillon M, Fenton AH, Watson PE. Bond Strength of composite to perforated and etch metal surfaces. *J Dent Rest* 1983 Jan;62:304
- 3- van Dalen A, Feilzer AJ, Kleverlaan CJ. In vitro exploration and finite element analysis of failure mechanisms of resin-bonded fixed partial dentures. *J Prosthodont.* 2008 Oct;17(7):555-61.
- 4- Parsa RZ, Goldstein GR, Barrack GM, LeGeros RZ. An in vitro comparison of tensile bond strengths of noble and base metal alloys to enamel. *J Prosthet Dent.* 2003 Aug;90(2):175-83.
- 5- Petrie CS, Eick JD, Williams K, Spencer P. A comparison of 3 alloys surface treatments for resin-bonded prostheses. *J Prosthodont.* 2001 Dec;10(4): 217-23.
- 6- Imbery TA, Eshelman EG. Resin-bonded fixed partial dentures: a review of three decades of progress. *J Am Dent Assoc.* 1996 Dec;127(12):1751-60.
- 7- Kohli S, Levine WA, Grisius RJ, Fenster RK. The effect of three different surface treatments on the tensile strength of the resin bond to nickel-chromium-beryllium alloy. *J Prosthet Dent.* 1990 Jan;63(1):4-8.
- 8- Re GJ, Kaiser DA, Malone WF, Garcia-Godoy F. Shear bond strengths and scanning electron microscope evaluation of three different retentive methods for resin-bonded retainers. *J Prosthet Dent.* 1988 May;59(5): 568-73.
- 9- Ghavam M, Hasani Tabatabaie M. Resin cement bond strength to noble and base metal alloys with two surface treatment techniques. *JIDA* 2011;23(2):79-86
- 10- Fonseca RG, de Almeida JG, Haneda IG, Adabo GL. Effect of metal primers on bond strength of resin cements to base metals. *J Prosthet Dent.* 2009 Apr; 101(4):262-8.
- 11- Renata GF, Santos PA, Isabella GH, Gelson LA. Effect of Metal Primers on Bond Strength of Resin

- Cements to Base Metals. *J Prosthet Dent.* 2009 Apr; 101(4):262-8.
- 12- Conceição EN, de Goes MF, Consani S. Chemical etching solutions for creating micromechanical retention in resin-bonded retainers. *J Prosthet Dent.* 1994 Mar;71(3):303-9.
- 13- Malek Nejad F, Ghavam Nasiri M. Effect of ultrasonic bath on base metal alloy-enamel bond strength after acid and sandblasting surface treatment. *J Mashad Dent Sch* 2003;27(1, 2):57-66.
- 14- Isidor F, Hassna NM, Josephsen K, Kaaber S. Tensile bond strength of resin-bonded non-precious alloys with chemically and mechanically roughened surfaces. *Dent Mater.* 1991 Oct;7(4):225-9.
- 15- Powers JM, Sakaguchi RL, Craig's Restorative Dental Materials. 13th ed., St. Louis, Mosby, 2012:224-31.
- 16- Abreu A, Loza MA, Elias A, Mukhopadhyay S, Looney S, Rueggeberg FA. Tensile bond strength of an adhesive resin cement to different alloys having various surface treatments. *J Prosthet Dent.* 2009 Feb;101(2):107-18.
- 17- Piwowarczyk A, Lauer HC, Sorensen JA. In vitro shear bond strength of cementing agents to fixed prosthodontic restorative materials. *J Prosthet Dent.* 2004 Sep;92(3):265-73.
- 18- Petridis H, Garefis P, Hirayama H, Kafantaris NM, Koidis PT. Bonding indirect resin composites to metal: part 2. Effect of alloy surface treatment on elemental composition of alloy and bond strength. *Int J Prosthodont.* 2004 Jan-Feb;17(1):77-82.
- 19- Hansson O, Moberg LE. Evaluation of three silicoating methods for resin-bonded prostheses. *Scand J Dent Res.* 1993 Aug; 101(4):243-51.
- 20- Mukai M, Fukui H, Hasegawa J. Relationship between sandblasting and composite resin-alloy bond strength by a silica coating. *J Prosthet Dent.* 1995 Aug;74(2):151-5.
- 21- Matsumura H, Shimoe S, Nagano K, Atsuta M. Effect of noble metal conditioners on bonding between prosthetic composite material and silver-palladium-copper-gold alloy. *J Prosthet Dent.* 1999 Jun;81(6):710-4.
- 22- Antoniadou M, Kern M, Strub JR. Effect of a new metal primer on the bond strength between a resin cement and two high-noble alloys. *J Prosthet Dent.* 2000 Nov;84(5):554-60.
- 23- Barkmeier WW, Latta MA. Laboratory evaluation of a metal-priming agent for adhesive bonding. *Quintessence Int.* 2000 Nov-Dec;31(10):749-52.
- 24- Yoshida K, Atsuta M. Effects of adhesive primers for noble metals on shear bond strengths of resin cements. *J Dent.* 1997 Jan;25(1):53-8.
- 25- Abreu A, Loza MA, Elias A, Mukhopadhyay S, Rueggeberg FA. Effect of metal type and surface treatment on in vitro tensile strength of copings cemented to minimally retentive preparations. *J Prosthet Dent.* 2007 Sep;98(3):199-207.
- 26- Silika N, Wincott PL, Vaughan D, Watts DC, Eliades G. Surface characterization of precious alloys treated with thione metal primers. *Dent Mater.* 2007 Jun;23(6):665-73.
- 27- Gates WD, Diaz-Arnold AM, Aquilino SA, Ryther JS. Comparison of the adhesive strength of a BIS-GMA cement to tin-plated and non-tin-plated alloys. *J Prosthet Dent.* 1993 Jan;69(1):12-6.