SHEAR BOND STRENGTH OF METAL/CERAMIC INTERFACE AFTER DIFFERENT SURFACE TREATMENTS: AN *IN VITRO* STUDY

RESISTÊNCIA AO CISALHAMENTO DA INTERFACE METAL/CERÂMICA APÓS DIFERENTES TRATAMENTOS DE SUPERFÍCIE: ESTUDO IN VITRO

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RESUMO

O objetivo do presente estudo in vitro foi verificar, através de teste de cisalhamento, a resistência de união da liga Wironia®light, à base de níquel-cromo sem berílio, sujeita a diferentes tratamentos de superfície, às cerâmicas Vita VM13 e Noritake. Foram confeccionados oitenta espécimes cilíndricos metálicos, com o auxílio de uma matriz de aço, nas dimensões de 4 mm de diâmetro por 4 mm de altura. Os espécimes foram divididos em oito grupos (n=10), de acordo com o tipo de tratamento superficial aplicado à liga metálica e com o tipo de cerâmica testada. Estes foram avaliados de acordo com os critérios de resistência ao cisalhamento e, com o auxílio de microscopia óptica, foi avaliada a área de cerâmica remanescente aderida ao metal após a fratura. Os corpos-de-prova do G6 (fabricados em Cerâmica Noritake com jateamento-26,401 ± 11,637 MPa) apresentaram maior resistência ao cisalhamento ($p > 0,05$) enquanto que os menores valores foram registrados no G4 (Cerâmica Vita com utilização de broca-13,440 ± 7,766 MPa). G6 (19425,4 µm2) apresentou a maior área de cerâmica aderida ao metal ($p > 0,05$) enquanto que o G4 (2310,2 µm2) apresentou a menor área. Concluiu-se que G6 obteve os valores mais altos de resistência ao cisalhamento e de remanescente cerâmico aderido à superfície metálica enquanto que o G4 obteve os valores mais baixos.

Descritores: Restaurações metalo-cerâmicas; ligas de níquel-cromo; porcelana dentária.

ABSTRACT

The aim of this in vitro study was to verify, by means of the shear test, the bonding strength of Wironia® light nickel-chrome alloy without beryllium, subjected to different surface treatments, to Vita VM13 and Noritake ceramics. Eighty cylindrical metal specimens were manufactured with aid from a steel matrix, measuring 4 mm in diameter by 4 mm height. The specimens were divided into eight groups (n=10), according to surface treatment applied to the metal alloy and type of ceramic tested. These were evaluated in accordance with shear strength criteria and, with the aid of optic microscopy the remained ceramic area adhered to metal after fracturing was evaluated. Specimens of G6 (manufactured with Noritake Ceramic treated with airborne particle abrasion-26.401 ± 11.637 MPa) presented the highest shear bond strength (p> 0,05), whereas the lowest values were recorded for G4 (the Vita Ceramic specimens bur treated -13,440 ± 7,766 MPa). G6 (19425,4 µm2) presented the biggest ceramic area adhered to metal (p> 0,05), whereas G4 (2310,2 µm2) presented the small area. In conclusion, G6 had the highest values for shear bond strength and metal adhere to surface, whereas G4 had the lowest values.

Descriptor: Metal-ceramic restorations, nickel-chrome alloys, dental porcelain.

INTRODUCTION

Modern Dentistry has a large quantity of materials and techniques at its disposal for restoring lost dental elements, in an endeavor to respect biological and esthetic aspects, and to preserve the remaining dental structure as far as possible (ARAÚJO, 2006)

Dental ceramic is an excellent esthetic material capable of mimicking the texture, color and translucence of the dental structure. However, because it has a high hardness index, that causes enamel abrasion of the antagonist teeth, and it is susceptible to fracture, the application of completely ceramic dentures is restricted (ANUSAVICE & RINGLE *et al.*, 1977).

With the aim of minimizing the risk of fracture of the parts and preserving the dental structure during prosthetic rehabilitation, metal-ceramic systems were developed, in which the porcelain is sinterized onto a metal infra-structure, and this has shown reliable chemical bond, high mechanical strength and good esthetic characteristics (MCLEAN, 2001).

Porcelain bond to metal is due to chemical, physical and mechanical forces (DEKON & GOIATO *et al.*, 2002). All these processes depend on the wettability of the metal surface with porcelain during the sinterization process(MCLEAN, 2001), and it is imperative for the alloys to have properties that are compatible with those of the ceramics, so that bonding occurs in the best manner (FERNANDES NETO & PANZERI *et al.*, 2006). The alloy surface preparation, its composition and the type of ceramic cooling are also interfering factors that must be taken into consideration in the results of the bond strength tests between the alloy and porcelain (FERNANDES NETO & PANZERI *et al.*, 2006).

The nickel-chrome alloys have been frequently used for making fixed metal-ceramic dentures because they cost less than gold alloys (VASCONCELLOS & GIOVANI *et al.*, 1999) and do not require sophisticated equipment with sensitive casting procedures, as titanium alloys do (ARAÚJO, 2006).

In this context, the aim of this study was to assess the metal bond strength of a nickel-chrome alloy without beryllium, to two types of dental ceramics used in metal-ceramic restorations, subjected to different surface treatments, and to verify the quantity of ceramic remaining adhered to the metal surface.

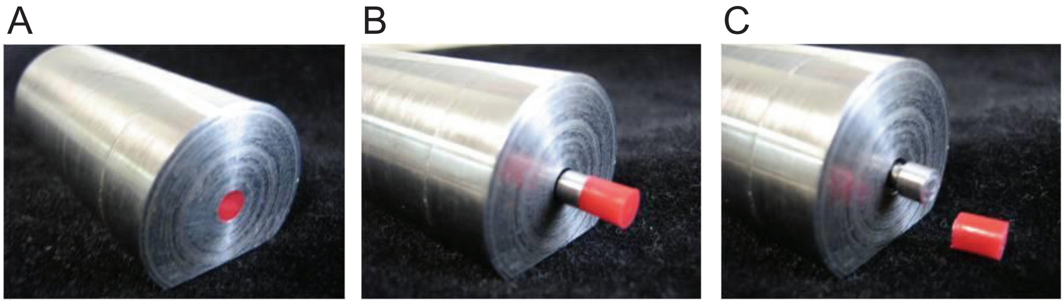

FIGURE 1
Eighty wax patterns were obtained through direct molding from a stainless steel matrix. A - Wax adapted inside the stainless steel matrix, B - metal rod triggered to remove the wax pattern: C - Wax pattern completed.

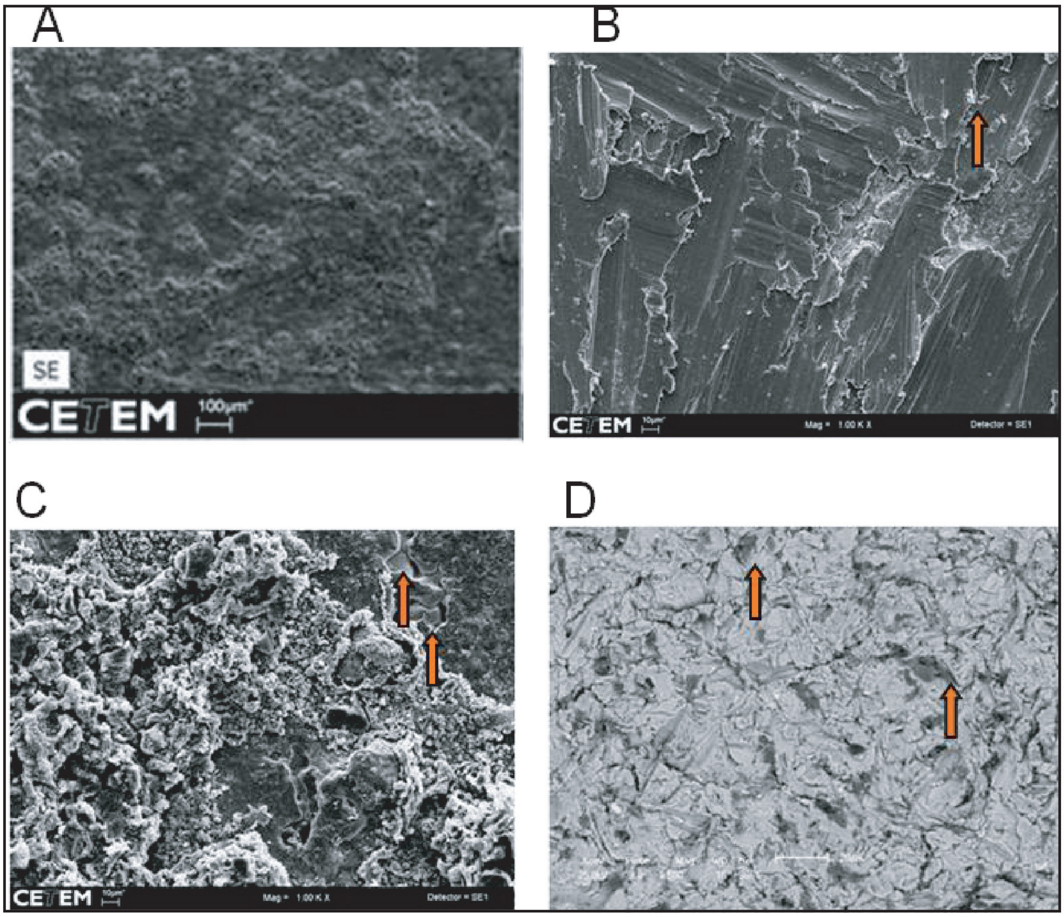

FIGURE 2
SEM images of different surface treatments on test specimens. A. Control with no treatment. B. Cylindrical diamond bur. C. 55% fluorhydric acid (Dentsply-Brasil) etching for 5 minutes. D. Aluminum oxide airborne particle abrasion (50 µm). (Scale: 10 µm/1KX).

MATERIAL AND METHODS

Eighty metal cylinders, measuring 4 mm in diameter by 4 mm high were waxed with the aid of a stainless steel matrix (Figure 1) and cast in nickel-chrome alloy without beryllium, Wironia®light (Bego - Bremen, Germany).

After being removed from the lining and cut from the sprue, the test specimens were steam cleaned subjected to no treatment (Figure 2A) or had received the following different surface treatments: use of a cylindrical diamond bur 835.104.016 (Komet - Germany) (Figure 2B), mounted on a straight part; 55% fluorhydric acid (Dentsply-Brasil) etching for 5 minutes (Figure 2C); aluminum oxide airborne particle abrasion (50µm) (Figure 2D).

Specimen surfaces were analyzed by Scanning Electronic Microscopy (SEM LEO, model S440) equipped with an X-ray spectrometry system (EDS) (Oxford Link, model ISIS) for microanalysis (Figure 3).

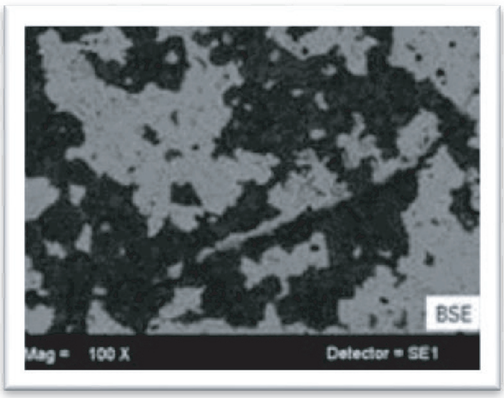

FIGURE 3
Energy dispersive spectrometry of X-rays, demonstrating the clear metal surface area and the dark area in the precipitation of oxides (scale: 10 µm/1KX).

CERAMIC APPLICATION AND FIRING

With the aid of a stainless steel matrix isolated with an insulating agent for ceramic (VITA– Bad-Sackingen, Germany), the ceramics Vita VM 13 (Vita – Bad-Sackingen, Germany), with their pre-opaque (Wash Opaque, Vita VM 13, Vita – Bad-Sackingen, Germany), and ceramic Noritake EX-3 (Noritake Kisai Co. – Nagoya, Japan) were applied to ten specimens of each type of surface treatment, using the incremental technique, in accordance with the manufacturers' recommendations.

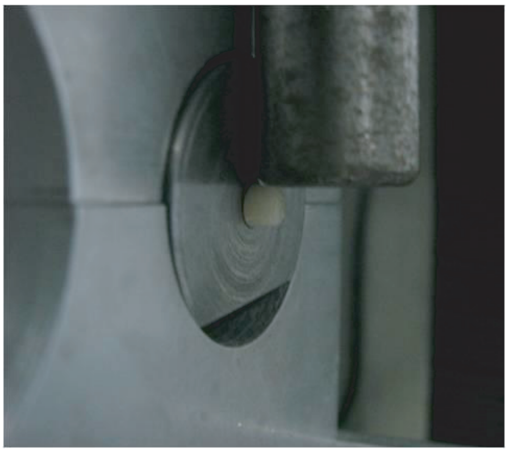

FIGURE 4
Shear test. Matrix with the specimen inside (A), attached to aluminum device (B), with the ceramic portion receiving the load of the active tip and flat device (C).

SHEAR TEST

All of the eighty test specimens, with their different surface treatments and ceramics were inserted into the matrix and taken to an EMIC, model DL 10.000 universal mechanical testing machine belonging to the Military Engineering Institute – IME - in order to perform the shear test (Figure 4). The force of a 50 Kgf load cell was applied on the exposed ceramic at a speed of 0.5 mm/min and shear fracture strength was recorded in MPa. After fracture of the test specimens, the areas of the ceramic remainders adhered to the metal were measured in µm2, by image analysis, with the aid of an optic microscope (ZEISS - Stemi 200C, Göttingen, Germany).

RESULTS

Table 1 shows the bond strength means obtained with the different types of surface treatment performed on the metal surface, recorded in MPa. After concluding the shear test, the remaining ceramic area adhered to the metal was measured with the aid of an optic microscope, and the measurements are shown in Table 2.

TABLE 1
Bond strength means (MPa) and standard deviations of two ceramic groups with different metal surface treatments.

Ceramic		Surface treatments	Mean	Standard Deviation
VITA	G1	No treatment	26.350	6.511
	G2	Aluminum Oxide airborne particle abrasion	25.154	4.760
	G3	Fluorhydric acid etching	17.604	9.009
	G4	With bur	13.440	7.766
NORITAKE	G5	No treatment	21.981	6.361
	G6	Aluminum Oxide airborne particle abrasion	26.401	11.637
	G7	Fluorhydric acid etching	21.973	4.512
	G8	With bur	25.928	8.005

Ceramic		Surface treatments	Mean	Standard Deviation
VITA	**G1**	No treatment	6817.00	3311.90
	G2	Aluminum Oxide airborne particle abrasion	15734.10	4468.80
	G3	Fluorhydric acid etching	18827.60	9628.99
	G4	With bur	2310.20	1518.44
NORITAKE	**G5**	No treatment	15379.90	9220.10
	G6	Aluminum Oxide airborne particle abrasion	19425.40	8365.68
	G7	Fluorhydric acid etching	11038.50	5296.72
	G8	With bur	12536.80	5783.27

TABLE 2
Mean values of ceramic remaining adhered to the metal surface in micrometers (µm)

The mean shear strength values were submitted to Shapiro-Wilk test that revealed p- value higher than 0.05 for all the groups, characterizing a normal distribution, allowing the analysis of variance (ANOVA) to be performed, in which a statistically significant difference was verified among the samples assessed ($p<0.05$).

The Tukey multiple comparison test, used to compare each group with the others, showed the existence of two homogeneous groups. The first homogeneous group was composed of G4 (13.440 ± 7.766 MPa), G3 (17.604 ± 9.009 MPa), G7 (21.973 ± 4.512 MPa), and G5 (21.981 ± 6.631 MPa). Whereas the second homogeneous group was composed of the groups G1 (26.350 ± 6.511 MPa), G6 (26.401 ± 11.637 MPa), G8 (25.928 ± 8.005 MPa), and G2 (25.154 ± 4.760 MPa), associated with the first homogeneous group excluding the data of G4. Therefore, the test specimens of G6 (26.401 ± 11.637 MPa) showed higher shear bond strength values, while the specimens of G4 (13,440 ± 7,766 MPa) showed the lowest results.

As regards the mean values of the ceramic remainders found, normal distribution was not observed in all the groups and it was not possible to perform parametric analysis. Thus, when analyzing the results with the normality test, it was found that there was no normal distribution ($p>0.05$) for G3. With the application of Kruskall-Wallis test, significant differences were found among the groups. Through the median analysis, it was concluded that G5 and G7 constitute a group, and G3 and G6 form another group, both being homogeneous. Furthermore, the specimens of G6 (19425.4 µm2) maintained the highest value of ceramic area adhered to metal while the samples of G4 (2310.2 µm2) obtained the lowest area.

DISCUSSION

Ceramic bonding to metal is performed during firing of the part, when the pores of the crystalline structure of the metal open, into which the fluid agents of the ceramic penetrate and remain fixed after cooling (NASCIMENTO & MARTINELLI *et al.*, 2003). This is attributed to physical factors such as the Van der Walls forces, chemical bond, and mechanical interaction (SILVER & KLEIN *et al.*, 1956).

In addition to the good clinical results and mechanical strength obtained (CHONG & BEECH, 1980), nickel-chrome alloys, when free of beryllium, allow the formation of a homogeneous layer of oxides, favoring the metal/ceramic bond (RESKALLA & CHAVES FILHO *et al.*, 2005). It also has reduced toxicity when exposed to the oral environment (LIN & BOWERS *et al.*, 2008, BEZZON & RIBEIRO *et al.*, 2001) due to its high resistance to corrosion(CHONG & BEECH, 1980).

Because it is a handcrafted process with dozens of variables to be accurately controlled, a metal-ceramic prosthesis must be made in accordance with the highest standards that regulate the laboratory stage, in order to avoid bond failure between the two materials, which in these cases, is usually associated with mechanical and chemical factors.

In the test developed by Itinoche in 1999 (TANGO & JÓIAS *et al.*, 2006),which uses cylindrical test specimens with ceramic superimposed on metal, it is necessary to standardize the specimens in order to obtaining reliable results. This is made feasible by using a stainless steel matrix that serves as a mold when making the samples, and for performing the mechanical test. Moreover, in this type of test, a lower probability of creating residual stress on the interface is observed; if this is associated with the shear forces, it could mask the results of the study (TANGO & JÓIAS *et al.*, 2006).

In their studies, Huang (2003) e Tango (2006) observed considerable metal/ceramic bond strength values in specimens treated with aluminum oxide airborne particle abrasion. In this research similar results were found, which can be attributed to airborne abrasion being capable of removing the excess unstable oxide layers formed during alloy casting, leaving the metal surface encrusted with aluminum that has a homogeneous composition and roughness, making it ideal for bonding (MACKERT & RINGLE *et al.*, 1988). This homogeneity of the oxide layer on the metal enables the wettability by the surface ceramic (ARAÚJO, 2006, ANUSAVICE & RINGLE *et al.*, 1977, MCLEAN, 2001, RINGLE & FAIRHURST *et al.*, 1979) with consequent diffusion of the metal ions, such as chrome and aluminum from the porcelain, forming an intermediate interface or layer (WARPEHA & GOODKIND, 1976). Thus, the oxide layers formed must probably have been sufficiently thick (DEKON & GOIATO *et al.*, 2002) to allow the perfect dissolution of ions, with interdigitations of the intermediate layer on the metal, resulting in good bonding (LUBOVICH & GOODKIND, 1977).

In the SEM image associated with energy dispersive X-ray spectrometry, the specimens that did not receive surface treatment showed a layer of oxide distributed irregularly on the metal, with high silicone content that diffused from the alloy to the surface during casting. In spite of the literature being unanimous in emphasizing the need for removing the excess oxides formed on the metal surface to form an ideal interface for bonding Groups G1 (26.350 ± 6.511 MPa) and G5 (21.981 ± 6.361 MPa) showed good results (ARAÚJO, 2006, ANUSAVICE & RINGLE *et al.*, 1977, FERNANDES NETO & PANZERI *et al.*, 2006, LIN & BOWERS *et al.*, 2008, HUANG, 2003, LUBOVICH & GOODKIND, 1977). Since the purpose of the study did contemplate measuring the thickness of the oxide layer shown in these specimens, there are several relevant factors to consider with regard to metal bonding to ceramic. Therefore, the satisfactory results may be justified by the action of factors such as: the harmonious interaction of thermal expansion coefficients that did not cause stress on the ceramic, inducing cracks (VASCONCELLOS & GIOVANI *et al.*, 1999, MACKERT & RINGLE *et al.*, 1988), and adequate cleaning of the metal surface, imperative for eliminating grease coming from handling, by means of using the steam (DEKON & GOIATO *et al.*, 2002) appliance to perform careful cleaning in this study.

Although metal surface treatment for formation of the interface was contemplated in this study, and the test specimens were not immersed in acid solutions, the result was similar to the findings of Araújo (2006); Huang (2003); Ringle *et al.* (1979) showing some points of corrosion on the metal surface. Some authors consider values above 10 MPa clinically acceptable for shear bond strength in metal/ceramic bonding (CHONG & BEECH, 1980). The nickel-chrome-based alloys with a high chrome (> 12%) and molybdenum (> 5%) content, such as the one used in this study, allows the formation of more stable oxide layers that are more resistant to corrosion(HUANG, 2003), forming fewer defects on their surfaces1. The application of fluorhydric acid for 5 minutes was capable of altering the metal surface, causing a diminished oxide layer, but not allowing it to become deficient or have an excess of failures that would interfere in bonding (MACKERT & RINGLE *et al.*, 1988, LUBOVICH & GOODKIND, 1977, SCOLARO & VALLE, 2002).

Alteration of the metal surface by the increase in roughness generated by the diamond bur does not necessarily mean an increase in fracture strength since this, among the mechanical interactions that occur, is the least important (LUBOVICH & GOODKIND, 1977). Therefore, roughness created by the bur could be excessively irregular, causing discontinuity of oxide layers, making surface wettability difficult and compromising bonding (Araújo, 2006). The use of diamond burs also leaves residues on the metal surface, since they are embedded in the alloy, prevent the correct diffusion of ions creating bubbles at the interface during porcelain firing, which weaken the bond (RINGLE & FAIRHURST *et al.*, 1979). Moreover, it was shown that the air-particle abrasion group exhibited significantly higher shear bond strength when compared to drilled group (DO NASCIMENTO & KIRSTEN MIANI *et al.*, 2012). However, the superior result of G8 when compared with G4 may be attributed to the uniformity of roughness and non-interference of other forces that regulate bonding.

It is important to emphasize the difference in ceramic processing; that is, Vita received a pre-opaque and opaque application (powder/liquid), while Noritake only received an opaque application (paste) because its kit does not contain a pre-opaque application. Although it was not the aim of this study, it could be that in spite of performing the ceramic application in accordance with the manufacturer's recommendations, the pre-opaque application may have interfered in the results.

In this study, few specimens showed cohesive fracture, and in the majority of cases, there were samples with total and partial debonding of the ceramic, corroborating the results of Scolaro and Valle (2002) who found samples with ceramic completely debonded from the metal. When the ceramic loosened from the metal, the failure occurred in the bond between the metal and oxide layers (SCOLARO & VALLE, 2002); and when there was ceramic remaining adhered to the metal, the problem was between the interface and the porcelain (ANUSAVICE & RINGLE *et al.*, 1977, MACKERT & RINGLE *et al.*, 1988). It seems to be clear that the higher the bond strength between the materials is, the larger will be the quantity of ceramic remaining adhered to the metal. Therefore, it may be observed that G6 offered higher shear bond strength and a larger area of adhered ceramic, while G4 showed lower shear bond strength values, with a reduced area of adhered ceramic.

CONCLUSION

Within the limitations of the methodology applied, and based on the results obtained, we may conclude that:

All the ceramics associated with different types of metal surface treatment showed clinically acceptable shear bond strength values.

The ceramic Noritake, whose surface was treated with aluminum oxide airborne particle abrasion, showed higher fracture strength at the metal/ceramic interface (26.401 ± 11.637 MPa), while the Ceramic Vita treated with a diamond bur showed the worst results (13.440 ± 7.766 MPa). The area of the ceramic remaining adhered to metal showed a direct relationship with the bond strength values of the different types of surface treatment performed in the shear test. Thus, Ceramic Vita treated with a diamond bur showed the smallest quantity of ceramic adhered to the metal after the shear test, while the group of Ceramic Noritake treated with aluminum oxide airborne particle abrasion showed the largest area of remaining ceramic.

REFERENCES

(REFORMATADA PARA VANCOUVER)

1. Araújo AMA. ***Caracterização microestrutural e tribocorrosiva de sistemas metalocerâmicos odontológicos do tipo Ni-Cr/Porcelana e Ni-Cr-Ti/Porcelana [Dissertação]***. Natal: Universidade Federal do Rio Grande do Norte; 2006.
2. Anusavice KJ, Ringle RD, *et al.* ***Adherence controlling elements in ceramic-metal systems. II. Nonprecious alloys.*** J Dent Res. 1977 Sep; 56(9):1053-61.
3. McLean JW. ***Evolution of dental ceramics in the twentieth century.*** J Prosthet Dent. 2001 Jan;85(1):61-6.
4. Dekon SFdC, Goiato MC, *et al.* ***Estudo comparativo da resistência de união porcelana-metal em função de sistemas de opacificação/Comparative study of strength of metal bonded to porcelain in function of opacification.*** Rev Odontol UNESP. 2002;31(2):159-69.
5. Fernandes Neto AJ, Panzeri H, *et al.* ***Bond strength of three dental porcelains to Ni-Cr and Co-Cr-Ti alloys.*** Brazilian Dental Journal. 2006;17:24-8.
6. Vasconcellos WA, Giovani R, *et al.* ***Uniäo metal/porcelana: efeito da pré-oxidaçäo e da consistência do opaco / The metal-ceramic bond: effect of previous oxidation and opaque consistency.*** Rev Assoc Paul Cir Dent. 1999 set-out;53(5):401-5.
7. Nascimento RMd, Martinelli AE, *et al.* ***Review Article: recent advances in metal-ceramic brazing.*** Cerâmica. 2003;49:178-98.
8. Silver M, Klein G, *et al.* ***Platinum-porcelain restorations.*** The Journal of prosthetic dentistry. 1956;6(5):695-705.
9. Chong MP, Beech DR. ***A simple shear test to evaluate the bond strength of ceramic fused to metal.*** Aust Dent J. 1980 Dec;25(6):357-61.
10. Reskalla HNF, Chaves Filho HDdM, *et al.* ***Estudo sobre resistência da união de porcelana em ligas de Ni-Cr com e sem berílio e ligas experimentais com titânio.*** J Bras Clin Odontol Integr. 2005;9(50/51):234-43.
11. Lin H-Y, Bowers B, *et al.* ***Metallurgical, surface, and corrosion analysis of Ni–Cr dental casting alloys before and after porcelain firing.*** Dental materials: official publication of the Academy of Dental Materials. 2008;24(3):378-85.
12. Bezzon OL, Ribeiro RF, *et al.* ***Castability and resistance of ceramometal bonding in Ni-Cr and Ni-Cr-Be alloys.*** J Prosthet Dent. 2001 Mar;85(3):299-304.
13. Tango RN, Jóias RM, *et al.* ***Avaliação da resistência da união metal-cerâmica utilizando diferentes agentes de união / Evaluation of metalceramic bond strength using different bonding agents.*** Cienc Odontol Bras. 2006;9(1):17-23.
14. Huang HH. ***Surface characterization of passive film on NiCr-based dental casting alloys.*** Biomaterials. 2003 Apr;24(9):1575-82.
15. Mackert JR, Ringle RD, *et al.* ***The Relationship Between Oxide Adherence and Porcelain-Metal Bonding.*** Journal of Dental Research. 1988 February 1, 1988;67(2):474-8.
16. Ringle RD, Fairhurst CW, *et al.* ***Microstructures in Non-precious Alloys Near the Porcelain-Metal Interaction Zone.*** Journal of Dental Research. 1979 October 1, 1979;58(10):1987-93.
17. Warpeha WS, Goodkind RJ. ***Design and technique variables affecting fracture resistance of metal-ceramic restorations.*** The Journal of prosthetic dentistry. 1976;35(3):291-8.
18. Lubovich RP, Goodkind RJ. ***Bond strength studies of precious, semiprecious, and nonprecious ceramic-metal alloys with two porcelains.*** The Journal of prosthetic dentistry. 1977;37(3):288-99.
19. Scolaro JM, Valle ALd. ***Bonding ceramic to metal: a comparison using shear tests / União da cerâmica ao metal: uma comparação utilizando testes de cisalhamento.*** Rev Fac Odontol Bauru. 2002;10(1):57-62.
20. do Nascimento C, Kirsten Miani P, *et al.* ***Shear bond strength between Ni-Cr alloy bonded to a ceramic substrate.*** Gerodontology. 2012;29(2):e909-e13.