SHEAR BOND STRENGTH BETWEEN METAL ALLOY AND A CERAMIC SYSTEM, SUBMITTED TO DIFFERENT THERMOCYCLING IMMERSION TIMES

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ABSTRACT

The aim of this study was to evaluate the shear bond strength of Co-Cr and Ni-Cr metal alloys and a specific ceramic, submitted to different thermocycling immersion times.
Sixty metal-ceramic specimens were confectioned and standardized in cylindrical format. Three thermocycling conditions were evaluated: without thermocycling, 3.000 cycles (5ºC/55ºC±1) with 30s of immersion time and 3.000 cycles (5ºC/55ºC±1) with 60s. The shear bond strength was performed in a universal testing machine, using a special device to concentrate the tension at the metal/ceramic interface during the test. The load was applied until fracture of the specimens. The data was statistically analyzed by ANOVA (two-way) and Tukey (p<0,05) test. The results didn't show significant statistic differences between the metal-porcelain combinations. Nevertheless, both metal-ceramic systems submitted to 60s of immersion time showed lower values compared to specimens without thermocycling.
It was concluded that the thermocycling immersion time of 1 minute affect the shear bond strength values for the Ni-Cr/porcelain and Cr-Co/porcelain systems.

Keywords: *Shear bond strength, alloys, thermocycling, metal-ceramic interface, ceramics.*

RESISTENCIA AL CIZALLAMIENTO ENTRE ALEACIONES METÁLICAS Y UN SISTEMA CERÁMICO SOMETIDOS A DIFERENTES TIEMPOS DE INMERSIÓN EN EL TERMOCICLAJE

RESUMEN

El objetivo de este estudio fue evaluar la resistencia a cizallamiento de aleaciones metálicas de Co-Cr y Ni-Cr; con un mismo tipo de cerámica, sometidos a diferentes tiempos de inmersión en el termociclaje.
Sesenta especímenes fueron confeccionados de forma standard en formato cilindrico. Tres condiciones de termociclaje fueron evaluadas: sin termociclaje, 3000 ciclos (5ºC/55ºC±1) con 30s y 3.000 ciclos (5ºC/55ºC±1) con 60s de tiempo de inmersión. El ensayo de cizallamiento fue realizado en una máquina universal usando un dispositivo para concentrar la tensión en la interfase metalocerámica durante el test. La carga fue aplicada hasta que ocurra la fractura de los especimenes. La información fue estadísticamente analizada por ANOVA (two-way) y el test de Tukey (p<0,05). Los resultados no mostraron diferencia estadísticamente significante entre las combinaciones metal-porcelana. Sin embargo, ambas combinaciones metalocerámicas sometidas a 60s de tiempo de inmersión mostraron valores más bajos en comparación con los especimenes del grupo sin termociclaje.
Fue concluido que el tiempo de inmersión de termociclaje de 1 minuto afectó los valores de resistencia de cizallamiento en los grupos de Ni-Cr/porcelana y Cr-Co/porcelana.

Palabras clave: *Resistencia al cizallamiento, aleaciones, termociclaje, interfase metalo-cerámica, cerámicas.*

INTRODUCTION

A considerable increase in the price of gold during the 1970s resulted in the development of alternative metallic systems. Two decades ago (1) the physical properties of Ni-Cr and Co-Cr base metal alloys were discussed and compared to those found in noble metals alloys. It was concluded that these base metal alloys have higher melting temperatures, require more critical handling and care with the melting technique, and are more difficult to finish, when compared to noble alloys. However, such disadvantages may be minimized due to advance in technology, material properties, and design advantages of these alternatives alloys for metal-ceramic restorations (2).

The use of base metal alloys is an unquestionable need, and the use of Co-Cr and Ni-Cr alloys in particular have permitted high quality treatment for a large number of patients with limited financial means (3). These and other non-precious alloys

TABLE 1. Alloys composition, porcelain-metal combinations, groups and number of samples.

Alloy composition in wt %	Porcelain/Metal	Groups	N
Ni 65, Cr 22.5, Mo 9.5, Nb 1, Si 1, Fe 0.5, Ce 0.5, C max 0.02 (%)	Vita VM13a/ Ni-Crb	Gr1	30
Co 61, Cr 26, Mo 6, W 5, Si 1, Fe 0.5, Ce 0.5,C max 0.02 (%)	Vita VM13a/ Co-Crc	Gr2	30

a VITA Zahnfabrik - Bad Säckinger- Germany . Batch # 7747
b Wiron 99 ®, Bego, Germany. Batch # 2798
c Wirobond ® Bego, Germany. Batch # 90114

have been developed and have become superior to the gold-based metals in several aspects, including mechanical and physical characteristics (3, 4).

Metal-ceramic restorations combine the metal strength and the esthetic of the porcelains by using laboratory techniques with the purpose of supplying a reasonable life time when the restorations are cemented intraorally. The success of the metal-ceramic restorations depends on the strength and integrity of the adhesion between metal and porcelain, the most susceptible site for occurrence of cracks (5-9). The cracks generally progress through the metal-ceramic interface or through the covering porcelain (6, 10).

Factors such as impact and fatigue, occlusal forces, and incompatibility between metal and porcelain physical properties may result in porcelain fracture, frequently of a cohesive nature (11-13). Due to the inherently brittle nature of ceramic restorative materials, failure under intraoral conditions of metal-ceramic restorations is not uncommon (14).

Thermocycling induces repetitive stress on metal-ceramic interface, which weakens the bond strength between the two components (15). These procedures are utilized to simulate the oral environment, and to infer the longitudinal clinical prognosis in vitro.

The primary requirement for the survival of a metal-ceramic restoration is the development of an efficient bond between the ceramics and metal alloys 16-18) but it has not been established yet. So, detailed knowledge of these adhesion mechanisms would help in the development and improvement of new systems (19).

The aim of this study was to evaluate the shear bond strength of Co-Cr and Ni-Cr metal alloys and a ceramic, submitted to different times of immersion and thermocycling.

MATERIALS AND METHODS

The metal-porcelain systems and the composition of each alloy are described in Table 1.

Specimen preparation

To create the metallic aspect of the specimen, a device was used to standardize the waxed parts (BEGO-Germany) with a pre-defined size (Figure 1). The first structure was a metallic ring that served as a matrix placed on a flat surface where the wax was melted. The purpose of the second structure was to remove the wax pattern that had been prepared.

Sixty wax patterns were made to obtain, using the lost wax casting technique, the correspondent metal structure of the specimens for each experimental group. Manufacturer's instructions for casting were followed. After divesting and removal of sprues, the cylindrical specimens were finished, since all specimens must have accurate dimensions to allow a perfect relation with the shear device.

Afterwards, the metallic structures were prepared for the application of the covering ceramic (VITA VM13). They were sandblasted with aluminum oxide (100µm) for 10 seconds at a 2 cm distance, under 2 bar pressure and 45 degree approximate angulation's. The structures were cleaned in an ultrasonic bath with isopropyl alcohol for 10 min and then dried.

To obtain the test specimens, two thin layers of opaque porcelain powder in a paste/liquid mix were applied on the 4mm side of the metal specimens using a brush and the firing and drying of the ceramic after each application. Each metal specimen was placed within one of the ten holes present in a Teflon matrix. So it was possible to apply the ceramic on the upper surface of the cylinders to a height of 4mm, resulting in metal-ceramic specimens with uniform dimensions.

TABLE 2. Firing cycle of VITA VM13 porcelain.					
	Inicial temperature	Drying time	Heating temperature/min	Initial temperature under vacuum	Final temperature under vacuum
Opaque firing	500° C	2’	75° C	890° C	890° C
1st dentin firing	500° C	6’	55° C	880° C	880° C
2nd dentin firing	500° C	6’	55° C	870° C	870° C
Source: VITA - Zahnfabrik – Germany.					

To prepare the dentin porcelain, the mixing liquid was added to the powder until a paste consistency was obtained. It was then condensed into the holes of the device and after removal the specimens were submitting to firing according to the manufacturer’s instructions (Table 2). A second application of these porcelain layers and another porcelain firing cycle was needed to compensate for the contraction generated during the first firing cycle, allowing achievement of the sample final dimensions as described in Figure 1.

Thermocycling test

The specimens within each group were randomly divided in three subgroups according the following thermal cycling conditions: (i) without thermal cycling; (ii) with 3.000 cycles (5ºC/55ºC±1) with 30s of immersion time; and (ii) 3.000 cycles (5ºC/55ºC±1) with 60s of immersion time.

Testing procedures

A cylindrical two independent pieces stainless steel device was used for shear bond strength testing (20, 21). (Figure 2). Piece A is cylindrical (Figure 3a) with a flat adaptation on its walls to allow the insertion of part B. The internal piece, B, had the same shape as the external piece A, and works like a piston during the mechanical test. On the flat surfaces

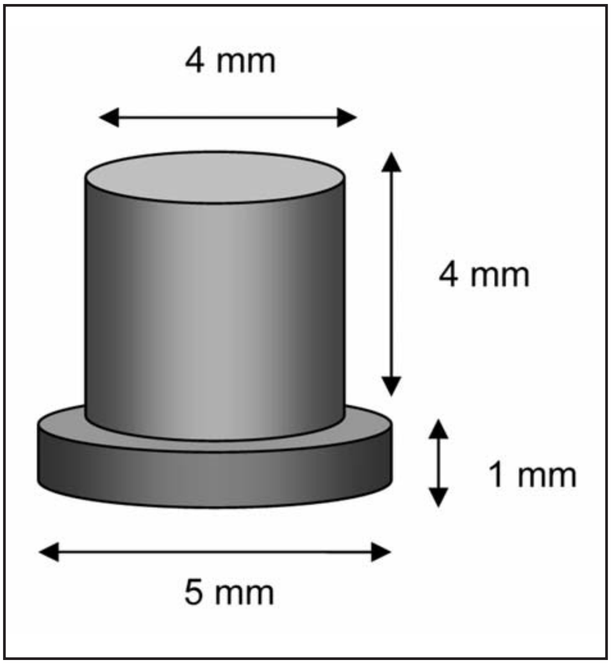

Fig. 1: Schematic illustration of specimen and its dimensions.

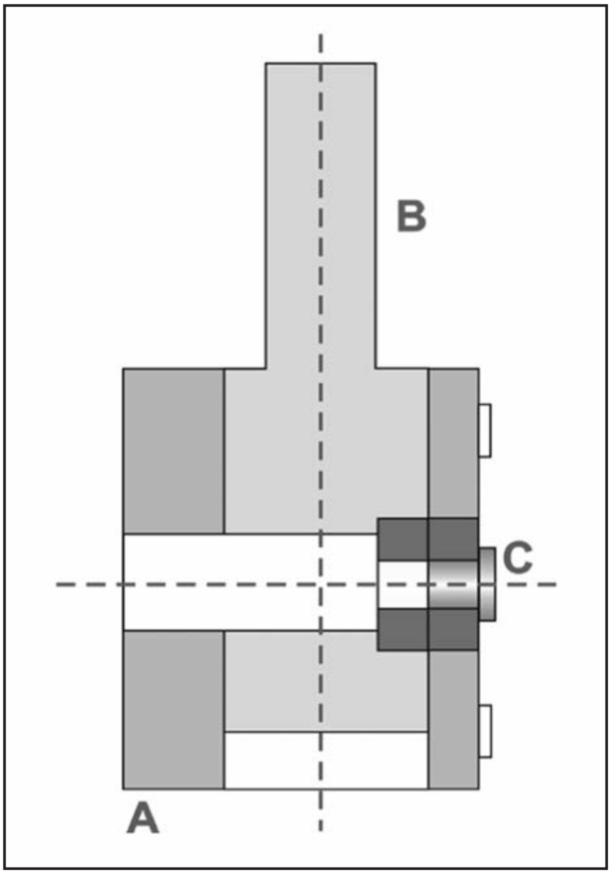

Fig. 2: Device for the mechanical test: a) external portion; b) internal portion; c) Specimen placed in the support.

TABLE 3. Means (standard deviation) obtained from shear bond strength test data for each group investigated.

	Alloys		
Ciclyng	Co-Cr	Ni-Cr	Overallmean±sd)
G1: Without cycling	85,68 ±(21,20)	101,02 (13,55)	93.35 (17.37)
G2: With cycling (30s)	74,71 (6,15)	79,91 (29.60)	77.31 (17.87)
G3: With cycling (1min)	76,05 (26,33)	70,04 (20,26)	73.04 (23.29)
Overall	78.81 (17.89)	83.65 (21.13)	

Values within brackets ares standard deviations.

TABLE 4. Tukey's test results.

Groups	Mean ± SD	Homogeneous Groups
(I)-non cycled	93,35	A
(II)-cycled (30s)	77.31	AB
(III)-cycled (60s)	73,04	B

of both A and B, 4 mm in diameter holes were drilled so that part A structure had an upper displacement in relation to the hole of part B. The matching of the holes allowed the introduction of the test specimen through both parts, at the same time. Thus, the ceramic portion of the specimen remained embedded within the structure A (Figure 2 and 3 b).

The apparatus containing a metal-ceramic specimen was placed on the universal testing machine (EMIC, model DL-1000- Equipments and Systems Ltda., *Sao Jose dos Pinhais* - PR -Brazil) with a 500-kg load cell. A crosshead speed of 0.5 mm/min was used to apply a compressive force to the upper cylindrical extension of part B, until fracture of the metal-ceramic test specimen occurred under shear loading.

The shear bond strength values were analyzed by ANOVA (two-way) and Tukey's test (significance level $p<0.05$).

RESULTS

The mean bond strength values, standard deviations and results of the Tukey's multiple comparison test are presented in Table 3 and 4.

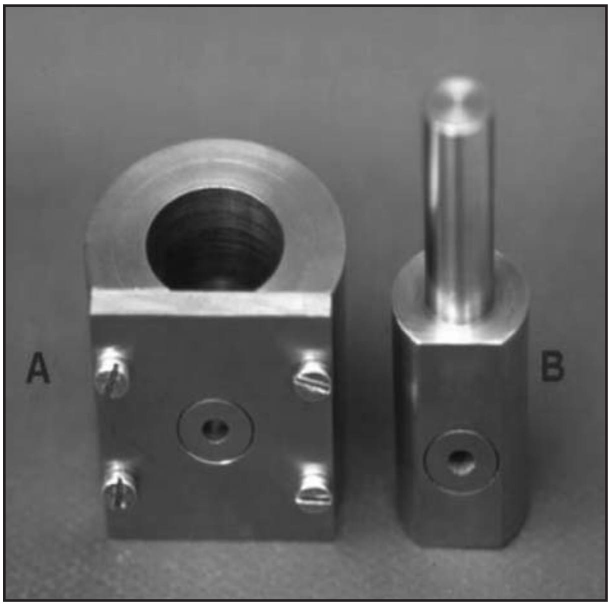

Fig. 3 a: Device for mechanical test: A) external portion; B) internal portion.

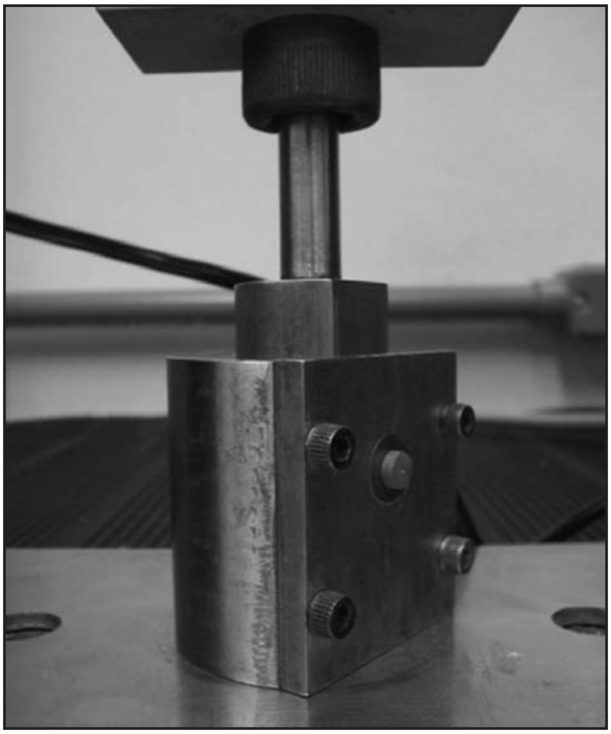

Fig. 3 b: Specimen in position for testing.

The ANOVA results showed that immersion bath condition was statistically significant while metal-porcelain system was not. Tukey's Multiple comparison test showed that (iii) cycled group (60s) values (73,045 ± 23,30MPa) were significantly lower in bond strength than (i) non cycled groups (93,35 ±17,375MPa).

DISCUSSION

The success of a metal-ceramic restoration depends primarily on strong adhesion between the porcelain and alloy. Many methods have been proposed to quantify such adhesion, but none is completely exempt from errors, due to the complexity of the ceramic/metal bonding (18, 22, 23).

Adhesion between ceramic and metallic base is a crucial point for clinical success, because a very complex stress situation occurs in the metal-ceramic interface (10). Several tests are capable of evaluating the metal-porcelain bond strength, such as flexural mode, twist, shear, tension or the combination of flexural and twist modes (24) all presenting advantages and disadvantages.

Several authors in the literature suggested the use of shear bond strength test (6, 8, 9, 20, 21, 23, 25, 26), and considered it as one of the most reliable methods to evaluate the bond strength because it concentrates the applied tension on the interface between two materials.

Bonding between porcelain and metal is possible by means of three mechanisms: Van der Waals' forces, mechanic retentions and chemical bonding according (17). Several studies demonstrated that preparation of the alloy surface resulted in an increase in bond strength between metal and porcelain surfaces. In our study it was used the sandblasting with Al_2O_3 (100µm) as a metal surface treatment.

In the present study, there was no statistically significant difference between Co-Cr/VM13 porcelain (78.81+-17.89 MPa) and Ni-Cr/VM13 porcelain (83.65+-21.13 MPa) systems for bond strength values. With the same type of test, Melo et al. found that the shear bond evaluation of the interface formed by base metal alloys (Co-Cr, Ni-Cr) with a dental porcelain product revealed no significant differences. Even, Bondioli and Bottino (21) used titanium-titanium porcelain combinations with the same method and obtained shear bond strength values for commercially pure titanium/Triceram (44.58±16.40 MPa) and commercially pure titanium/TTitankeramik (48.28±21.29 MPa) lower than ours. Other studies (8, 23, 24, 27, 28) using the shear test with different methods and other types of alloys, reported results varying from 15 MPa to 60 MPa. The variation of the results in the studies is high, due mainly to the inexistence of a universal methodology for evaluation of bond strength of the porcelain fused to metal substrate. But, the literature has described that shear bond strength mean greater than 10MPa indicate clinically satisfactory results (23, 28).

Temperatures and pH changes in the oral environment may influence the time service of porcelain- metal restorations. The behavior of metal-ceramic interface has been related under those conditions. Several variables in the thermocycling procedure such as number of cycles, temperatures changes and bath immersion time have turned the comparison among the studies that include thermocycling tests difficult (29).

Poljak-Guberina et al. (28), stated that a decrease in fatigue strength of metal-ceramic systems (Ag-Pd alloy/hydrothermal ceramic) occurs with thermocycling (1000 cycles, 5ºC/55ºC±1ºC), and failures occur with 30 to 50% lower number of cycles on thermocycling group than on non-thermocycled ones. However, Probster et al. (30) reported than the bond strength of metal-porcelain systems (Pd-Ag alloy/conventional porcelain, commercially pure titanium/specific ceramic and Ti-6Al-4V alloy/specific porcelain) were not affected when submitted to thermal cycling.

Tróia et al. (15) reported that thermocycling (3000 cycles, 5ºC/55ºC±2ºC, with 10s immersion time), to simulate an oral environment did not affect the strength of interface metal-porcelain combination (low fusing porcelain bonded to commercially pure titanium and Ti-6Al-4V alloy), but they suggest than long immersion periods in each bath would be able to generate a significant quantity of tensions on the interface metal-porcelain. The present study revealed that bond strength values in the specimens after the thermocycling with 1 minute of bath immersion (73,045 ± 23,295 MPa) were lower than after 30 s of bath immersion (77.31 ± 17.87 MPa).

CONCLUSION

Based on the present results, it is possible to conclude that the thermocycling did not affect the bond strength between metal-porcelain combinations. However, thermocycling with one minute immersion time influenced shear bond strength values in each experimental group.

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REFERENCES

1. Johnson A, Winstanley RB. The evaluation of factors affecting the castability of metal ceramic alloy—investment combinations. Int J Prosthodont 1996; 9:74-8.
2. Baran GR. Selection criteria for base metal alloys for use with porcelains. Dent Clin of North Am 1985; 29:779-87.
3. Bezzon OL. Allergic sensitivity to several base metals: A clinical report. The J Prosthet Dent 1993; 69:243-6.
4. Grimaudo NJ. Biocompatibility of nickel and cobalt alloys. Gen Dent 2001; 49:498-505.
5. Bowers JE, Vermilyea SG, Griswold WH. Effect of metal conditioners on porcelain-alloy bond strength. J Prosthet Dent 1985; 54:201-3.
6. Daftary F, Donovan T. Effect of four pretreatment techniques on porcelain-to-metal bond strength. J Prosthet Dent 1986; 56:535-9.
7. Drummond JL, Randolph RG, Jekkals VJ, Lenke JW. Shear testing of the porcelain-metal bond. J Dent Res 1984; 63:1400-1.
8. Malhotra ML, Maickel LB. Shear bond strength in porcelain-metal restorations. J Prosthet Dent 1980; 43:397-400.
9. O´Connor RP, Macket JR, Myers ML, Parry EE. Castability opaque masking and porcelain bonding of 17 porcelain-fused-to-metal alloys. J Prosthet Dent 1996; 75:367-74.
1. Suanswuan N, Swain MV. New approach for evaluating metal-porcelain interfacial bonding. Inte J of Prosthodont 1999; 12:547-52.
10. Zhukovsky L, Godder B, Settembrini L, Scherer W. Repairing porcelain restorations intraorally: techniques and materials. Compend Contin Educ Dent 1996; 17:18-28.
11. Pameijer CH, Louw NP, Fischer D. Repairing fractured porcelain: how surface preparation affects shear force resistance. J Am Dent Assoc 1996; 127:203-209.
12. Chung KH, Hwang YC. Bonding strengths of porcelain repair systems with various treatments. J Prosthet Dent 1997; 78:267-274.
13. Kelsey WP, Latta MA, Stanislav CM, Shaddy RS. Comparison of composite resin-to-porcelain bond strength with adhesives. Gen Dent 2000; 48:418-421.
14. Tróia MG Jr, Henriques GE, Nobilo MA, Mesquita MF. The effect of thermal cycling on the bond strength of low fusing porcelain to commercially pure titanium-aluminium-vanadium alloy. Dent Mater 2002; 19:790-6.
15. Bagby M, Marshall SJ, Marshall Junior GW. Metal ceramic compatibility: a review of the literature. J Prosthet Dent 1990; 63:21-5.
16. Lacy M. The Chemical nature of dental porcelain. Dent Clin North Am 1977; 21:661-7.
17. Anusavice KJ, Dehoff PH, Fairhurst CW. Comparative evaluation of ceramic-metal bond tests using finite element stress analysis. J Dent Res 1980; 59:608-13.
18. Hegedeus C, Daróczi L, Kökényesi V, Beke DL. Comparative microstructural study of the diffusion zone between Ni-Cr alloy and different dental ceramics. J Dent Res 2002; 81:334-7.
19. Melo RM, Travassos AC, Neisser MP. Shear bond strengths of a ceramic system to alternative metal alloys. J Prosthet Dent 2005; 93:64-9.
20. Bondioli IR, Bottino MA. Evaluation of shear bond strength at the interface of two porcelains and pure titanium injected into the casting mold at three different temperatures. J Prosthet Dent 2004; 91:541-547.
21. Lubovich RP, Goodkind RJ. Bond strength studies of precious, semiprecious, and nonprecious ceramic-metal alloys with two porcelains. J Prosthet Dent 1977; 37:288-99.
22. Chong MP, Beech DR. A simple shear test to evaluate the bond strength of ceramic fused to metal. Aust Dent J 1980; 25:357-61.
23. Hammad IA, Stein RS. A qualitative study for the bond and color of ceramometals – Part I. J Prosthet Dent 1990; 63:643-53.
24. Gavelis JR, Lim SB, Guckes AD, Morency JD, Sozio RB. A comparison of the bond strength of two ceramometal systems. J Prosthet Dent 1982; 48:424-8.
25. Stannard JG, Marks L, Kanchanatawewat K. Effect of multiple firing on the bonding strength of selected matched porcelain-fused-to-metal combinations. J Prosthet Dent 1990; 63:627 – 9.
26. Kimura H, Horng CJ, Okazaki M, Takahashi J. Oxidation effects on porcelain-titanium interface reactions and bond strength. Dent Mat 1990; 9:91-9.
27. Poliak-Guberina R, Catovic A, Jerolimov V, Franz M, Bergman V. The fatigue strength of the interface between Ag-Pd alloy and hydrothermal ceramic. Dent Mat 1999; 15:417-20.
28. Gale MS, Darvell BW. Thermal cycling procedures for laboratory testing of dental restorations. J Dent 1999; 27:89-99.
29. Probster L, Maiwald U, Webwe H. Three point bending strength of ceramics fused to cast titanium. Eur J Oral Sci 1996; 104:313-9.