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Comparative analysis of ceramic flexural strength in co-cr and ni-cr alloys joined by TIG welding and conventional brazing

Adaias Oliveira Matos[1*], Cristiane de Castro C. Castelo Branco[2], Eliza Burlamaqui Klautau[3], Bruno Pereira Alves[3].

[1] Doctoral Student, Department of Prosthodontics and Periodontology, Piracicaba Dental School, University of Campinas (UNICAMP), Av Limeira, 901, Piracicaba, São Paulo 13414-903, Brazil.

[2] Master Degree Student, Department of Prosthodontics, Dentistry College, Federal University of Pará (UFPA), Rua Augusto Corrêa, 01, Belém, Pará 66075-110, Brazil.

[3] Permanent Professor, Department of Prosthodontics, Dentistry College, Federal University of Pará (UFPA), Rua Augusto Corrêa, 01, Belém, Pará 66075-110, Brazil.

Aims: The purpose of the present study was to evaluate the flexural strength of specimens made of nickel-chromium (Ni-Cr) and cobalt-chromium (Co-Cr) alloys and joined by tungsten inert gas (TIG) welding and conventional brazing. Ni–Cr and Co–Cr base metal specimens (n = 40, each) were cast and welded by TIG or brazing. The specimens were divided into six groups (2 base metals, four welded specimens). Ceramic systems were applied to the central part of all the specimens. A three-point bending test with a velocity of 0.5 mm/m was performed on the specimens up to the point of the first ceramic bond failure by measuring the flexural strength. Data were analyzed using two-way ANOVA and Bonferroni's tests. Conventional welding showed the lowest flexural strength results for both alloys, while the TIG weld and the control group presented with varying bond strengths for the alloys studied. We concluded that TIG welding was superior to the conventional welding method for both Ni–Cr and Co–Cr alloys with regard to the flexural strength of the ceramic.

Keywords: Ceramics, Welding, Dental Alloys

Corresponding author:
Av. Limeira, 901,
Piracicaba, SP, Brazil 13414-903,
Tel.: + 55-19-984333415;
E-mail: adaiasmatos@hotmail.com

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Introduction

Despite several ongoing studies on the development and improvement of pure ceramic systems, metal-ceramic fixed prostheses continue to be of great clinical importance owing to their versatility and feasibility in various therapeutic modalities and affordable cost[1-3]. The metal-ceramic system produces a restoration in which, the physical properties of porcelain and metal are used for mutual reinforcement, but if the ceramic gets detached, metal exposure is inevitable leading to the loss of esthetics[4,5]. Thus, the union between metal and ceramic is essential for successful restoration that involves longevity in the oral cavity[6].

Basic metal alloys have been used as alternatives for metal-ceramic prosthetics owing to their low cost compared to other alloys[7]. This has enabled the employment of high quality treatment for a large number of patients, especially those with low purchasing power[2,7]. However, difficulty in handling, susceptibility to oxidation, high melting temperature, and inferior finishing are the main disadvantages of these alloys[3,8]. The advantages of basic metal alloys include high fracture strength, high modulus of elasticity, rigidity, and resistance to permanent deformation[9,10].An additional advantage of the metal structure of a fixed prosthesis is its resistance to plastic deformation[11].

In addition to mechanical properties, metals must be biocompatible, resistant to corrosion, and easy to manipulate during the preparation of prostheses. Nickel–chromium (Ni–Cr) alloys are the most commonly used basic metal alloys for metal-ceramic restorations[12,13]. However, because of the potential health problems associated with beryllium and nickel, the cobalt–chromium (Co–Cr) alloy has been used as an alternative despite its inferiority to Ni-Cr alloys[3].

When the metal framework of the prosthesis does not fit perfectly on the abutments, the metallic infrastructure is sectioned, and the welding process is carried out after adjusting to the abutments; this procedure aims to improve the adaptation of prostheses to abutments or implants, thereby restoring the force previously lost following the sectioning of the metallic infrastructure[14]. The joining of metals in prosthetic structures can be achieved by brazing or via laser or tungsten inert gas (TIG) welding[9,15].

In the brazing process, the bonding between metals is produced by heating an additional metal that has a melting point lower than that of the base metal to a suitable temperature. TIG welding process involves joining metal structures by heating and melting them through an electric arc established between a tungsten electrode and the parts to be fused[16]. The most commonly used gases during TIG welding are helium and argon[10,17]. Although the use of TIG welding in dentistry is uncommon, some studies show the superiority of this technique compared to conventional brazing[18,19]. Several studies have evaluated the bond strength of porcelain in different alloys[7,20-22]. However, few studies have evaluated the bond strength of ceramics in regard with TIG welding or brazing.

Therefore, the aim of the present study was to compare the ceramic bonding strength between areas in the Co–Cr and Ni–Cr alloys that underwent TIG welding and conventional brazing. The null hypothesis was that there would be no significant differences between the Co–Cr and Ni–Cr alloys.

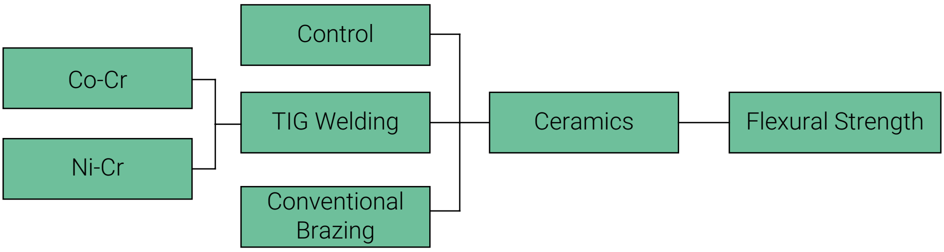

Figure 1. Flowchart of experimental procedure.

Material and methods

Experimental design

Co–Cr (Fit Cast Cobalt-Talladium do Brasil) and Ni–Cr (Fit Cast SB Plus-Talladium do Brasil) alloys were joined by TIG welding or conventional brazing, and ceramic coated (Vita VM13-Germany) in the center of the specimens[23].

Two control groups with Co–Cr and Ni–Cr alloys (no welding), and four test groups (two Co–Cr alloys and two Ni–Cr alloys) joined by TIG welding and conventional brazing (10 samples in each group) were used in this study.

Obtaining patterns for casting

Initial patterns of thermopolymerizable acrylic resin (Jet, Artículos Odontológicos Clássico Ltda, São Paulo, SP, Brazil) were made using the following dimensions: 25 mm in length, 3 mm in width and 1 mm in thickness; and 50 mm in length, 3 mm in width and 1 mm in thickness.

The inclusion was performed by arranging the resin patterns parallel to each other and joining them using wax (Kota, Indústria e Comércio, São Paulo, SP, Brazil). The assembly was mounted on a silicone ring for inclusion before coating.

Elimination of acrylic

A Nº5 silicone ring was filled with coating (Microfine1700, Talladium, Curitiba, Pr, Brazil) at a ratio described by the manufacturer (powder:liquid, 90 g of powder to 23 ml of liquid; the liquid solution comprised 18 ml of liquid and 5 ml of distilled water), mixed for 10 s, and vacuum-spatulated (VRC-VRC Equipamentos-Guarulhos-SP-Brazil) for 30 s. After 20 min in the ring, the hot coating was placed in an electric oven (EDGCON 5P, Equipamentos e Controlles LTDA, São Carlos, SP, Brazil) at an initial temperature of 400°C for 30 min.

Subsequently, the temperature was raised to 950°C, and maintained for 20 min. After the heating cycle, the temperature was reduced and the ring was removed (at 850°C for Ni–Cr alloys and 900°C for Co–Cr alloys).

Induction casting of Co-Cr and Ni-Cr alloys

Forty patterns from the 25-mm Co–Cr alloy casting and 10 patterns of the 50-mm casting were used. Likewise, 40 and 10 patterns from the 25-mm and 50-mm Ni–Cr alloy casting, respectively, were used in this study. The Co–Cr and Ni–Cr alloys were weighed (V.H Equipamentos, Araraquara, SP, Brazil).

Initially, the alloys were distributed inside the ceramic crucible following which, the induction centrifugation system (Power Cast Red - EDG - São Carlos - SP - Brazil) was activated. After centrifugation and metal cooling, the strips were finished with carbide tungsten minicut drills.

Conventional Brazing

In order to carry out the brazing process, an acrylic device was fabricated to position the metal specimens without any spaces between them. The specimens were attached with chemically activated resin (Duralay, Reliance Dental Company, USA) through the hole in the device, and the resin-wrapped area was covered with utility wax (Wilson, Polidental Indústria, Cotia, SP, Brazil).

The high-temperature coating (Easy-Stack-Stage) was prepared according to the manufacturer's instructions and spatulated with water. It was hand-manipulated for 40 s, and the hardening reaction was expected to occur within 20 min. The coating block was placed in the oven (EDG equipment) along with the specimens at 540°C for 20 min. After heating, the block was removed from the oven and cooled slowly to room temperature.

The flame was regulated until it achieved a 15-mm long blue cone using a gas torch (liquefied petroleum gas; EDG equipment) with a single-hole nozzle. The central parts of the strips were heated until bright red. This coloration was obtained by placing the strips on to the side of the torch (Tilite-Talladium) following which, the flame was rapidly passed throughout the region of the weld[24].

TIG welding

TIG welding was performed using TIG NTY 60C welding equipment (kernit Indústria Mecatrônica Ltda, Indaiatuba, SP, Brazil). Argon flow was released when the system was activated, forming an oxygen-free region and triggering the electric current. The specimens were positioned in an acrylic device containing a channel in which they could be accommodated without any spaces between them[17].

Application of ceramics

After the welding processes, the specimens were finished using drills, ground in polystyrene (Arotec, Cotia, SP, Brazil), blasted with aluminum oxide at a particle size of 110 µm and compression of 5.1 kgf/cm, and they were placed on a vibrator with isopropyl alcohol for waste removal.

An acrylic matrix was prepared to delimit the area of application of the ceramic to 8 ± 0.1 mm in length, 3 ± 0.1 mm in width, and 1 ± 0.1 mm in thickness. Ceramic was applied to the center of the weld area, on one side of the metal specimens.

Initially, the specimens were pre-oxidized in an oven (Ceramsinter-EDG). Following the application of an opaque layer, the specimens were subjected to firing; this process was performed twice. Dentin layers were applied to the established dimensions and glazing of the ceramic surface was finally achieved[3].

Flexural test

The specimens were submitted to a 3-point bending test in a test machine (Kratos Equipamentos, São Paulo, SP, Brazil) equipped with a 50 N load and a speed of 0.5 mm/min. The coated ceramic face was positioned down toward the rupture between the ceramic and metal substructure. The maximum force (N) was recorded until the first fault, for each test body.

The flexural strength was calculated according to the following formula:

$$\Sigma = \frac{3Pl}{2bd^2},$$

where P is the maximum force (N), l is the distance between the supports (mm), b the sample width (mm), d the sample thickness (mm), and Σ is the the flexural strength (MPa)[3].

Statistical analysis

Flexural strength (MPa) data were analyzed by two-way ANOVA (factor 1: framework type; factor 2: welding type). Bonferroni tests were performed to compare the mean values among groups (α = 0.05; SPSS version 20.0 - Statistical Package for the Social Sciences, Inc.). A p value of 0.05 was considered significant.

Results

Two-way ANOVA revealed a significant difference in the bond strength of ceramic between the welding types and framework types when subjected to flexural strength test.

Figure 2 displays the results of flexural strength between the ceramic and areas TIG welded areas and brazing in Co–Cr and Ni–Cr alloys. The best flexural strength results were numerically observed in the welding type for TIG welding and framework type for Ni–Cr alloy. TIG welding in the Co–Cr alloy ($p < 0.05$) and Ni–Cr alloy ($p < 0.05$) increased the bond strength between the ceramic and TIG welded area when compared with the group with welding to brazing. Flexural strengths in the control (P = 0.000) and TIG groups (P= 0.011) were significantly affected by the

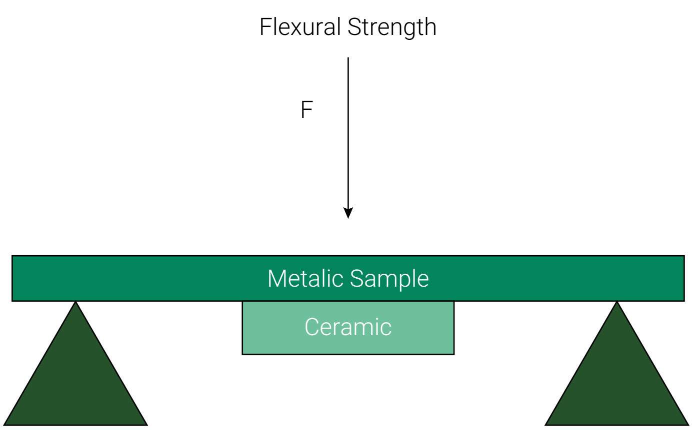

Figure 2. Flexural Strength assay

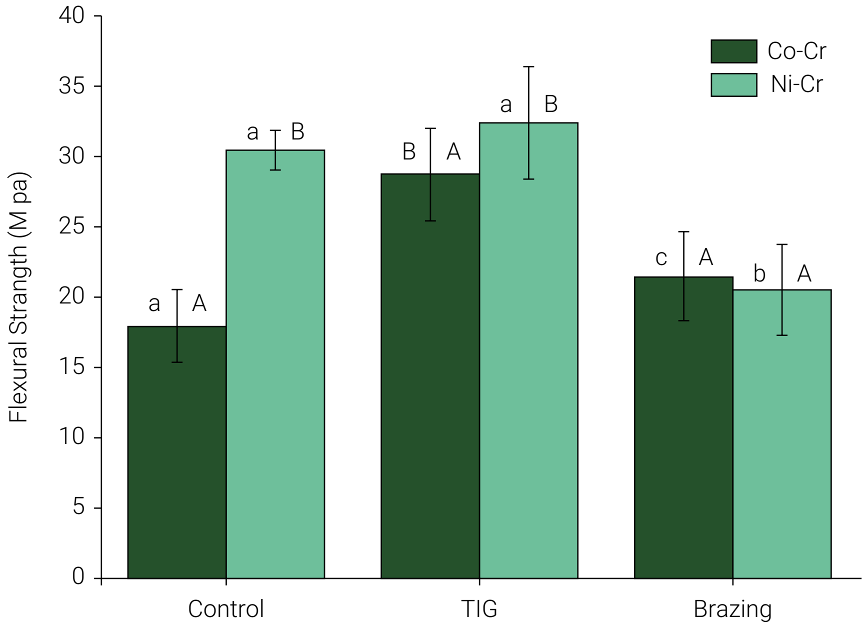

Figure 3. Mean flexural strengths (MPa) in the control, TIG, and brazing groups based on the different welding and framework types. The different lower case letters represent significant differences among the same type of alloy associated with the different types of welding methods used. The capital letters represent significant differences among the different structures related to the same of type welding method used.

type of framework used. On the one hand, welding types were significantly different for the Co–Cr alloy in all groups ($p < 0.05$), whereas, on the other hand, the Ni–Cr alloy demonstrated significant decrease in flexural strength for conventional brazing when compared to welding ($p < 0.05$).

Discussion

Dental ceramics possess biocompatibility, color stability, and wear resistance; however, they also have low flexural strength, and one method to address this disadvantage is to attach the ceramic to a substructure of metal alloys[24]. The welding process is widely used during the manufacture of fixed dental prostheses. Currently, several techniques are employed, and each has its own advantages and disadvantages[14,25].

The conventional technique involves several critical steps including temperature control and exposure time of the metal to the flame for proper solder flow; the technique is even more challenging when Ni–Cr or Co–Cr alloys are involved because of difficulty in the removal of oxides[21]. Both temperature and flame control of the torch can influence the conventional brazing method by altering the oxide layer formed on the surface of these alloys, which interfere with bonding of the ceramic to the metal during the welding process; the incorporation of oxygen results in porosity in the welded area, making it less resistant to flexion[18].

Thus, the results presented in the brazing group indicate that this welding method reduces of the flexural strength of Co–Cr and Ni–Cr alloys by interfering with the bonding of the ceramic to the metal. Brazed areas showed less flexural strength when compared to the welded areas of TIG.

In the case of Ni–Cr and Co–Cr alloys, bending mainly occurs between the metal and ceramic coating in the passive layers. The Co–Cr alloy is less resistant to bending and has higher elasticity compared to the Ni–Cr alloy, which possesses comparatively higher bending strength and lower elasticity. Flexural strength was higher in the Ni–Cr alloy than in the Co–Cr alloy in the control and TIG groups. This may be explained by the fact that this process has the advantage of using the minimum amount of heat, thereby reducing the area affected by heat and the production of free oxygen in the region; this results in a decrease in oxide residues formed during welding, and facilitates the maintenance of alloy properties[25].

The advantages of TIG welding over conventional welding include the realization of the weld in the working model itself, reduction in working time and consequently, occurrence of inherent failures during the welding process, and production of less heat, which allows for welding after the application of ceramics[25]. The TIG weld used for bonding ceramic to metal presented with more resistance to flexion only in the Co–Cr alloy group compared to the control groups. Both Ni–Cr and Co–Cr alloys can be satisfactorily used in the clinics. Nevertheless, further in vitro and in vivo studies simulating the application of masticatory loads and using biocompatibility tests on these welds are warranted.

Conclusion

Within the limitations of the present in vitro study, we draw the following conclusions:

The bond strength of ceramic to metal using the TIG welding process was superior to that using the conventional brazing process.

Different alloys with the same type of weld showed no differences in the bond strength of ceramic only for conventional brazing process.

Co–Cr alloys may be used as an alternative to Ni–Cr alloys.

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