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Evaluation of ceramic flexural strength of a cobalt-chromium alloy subjected to airborne particle abrasion and tungsten inert gas welding

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Aim: The aim of this study was to evaluate the influence of tungsten inert gas (TIG) welding and airborne particle abrasion using aluminum oxide particles on the flexural strength of a joint between ceramic and cobalt-chromium alloys. **Methods:** The specimens were cast and welded using TIG, then divided into 6 groups (n = 10) and subjected to blasting with 250 µm, 100 µm, and 50 µm aluminum oxide particles. Ceramic systems were applied to the central part of all specimens. A three-point bending test using a velocity of 0.5 mm/m was performed on the specimens to measure flexural strength. Data were analyzed using two-way analysis of variance and Tukey's test. **Results:** TIG welding demonstrated the lowest resistance compared with the non-welded groups. Airborne particle abrasion using 250 µm aluminum oxide particles demonstrated greater resistance in the welded groups ($p < 0.05$). Mixed faults were found in all specimens. **Conclusion:** TIG welding decreased the bond strength, and the particle size of aluminum oxide did not affect the metal-ceramic bond in groups without TIG welding.

Keywords: Dental materials. Dental soldering. Dental porcelain.

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Introduction

Although metal-free restorations are a growing trend in dentistry, metal-ceramic restorations have been widely used in dental practice due to the excellent clinical performance and feasibility for fabricating fixed partial dentures and single crowns. For this, metallic alloys, such as cobalt-chromium (Co-Cr), are used because of their biocompatibility and low cost compared with noble metallic alloys[1-3].

The formation of an adhesive layer between metal and ceramic is necessary for the longevity of restorations. There are three possibilities of retention, including Van der Waals forces, micromechanical retention and chemical bonding, which is the main factor, and is characterized by the exchange of oxides between the metal and the oxidizable elements of ceramics[4-6].

Several surface treatments have been studied, such as airborne particle abrasion (APA) with aluminum oxide (Al_2O_3) particles, which is a commonly used method for providing mechanical retention, resulting in the formation of an oxide layer that facilitates adhesion of the porcelain and increases the metal surface energy[7-10]. However, the size of the particles used in this process varies. Therefore, it is important to define possible interactions between these different size particles and metal-ceramic adhesion in Co-Cr alloys.

Marginal adaptation and passive fit are one of the most important requirements of dental prosthesis. Prosthetic infrastructure fused in a single piece may increase the probability of lack of fit. A solution to this problem is to section the metallic infrastructure and weld the abutments. This procedure is used to achieve the best adaptation and uniform distribution of forces, thus reducing trauma to the supporting teeth[11-13]. In the case of implants, this distribution becomes even more important, because they do not have the physiological mobility necessary to compensate for distortions resulting from adaptation errors[14].

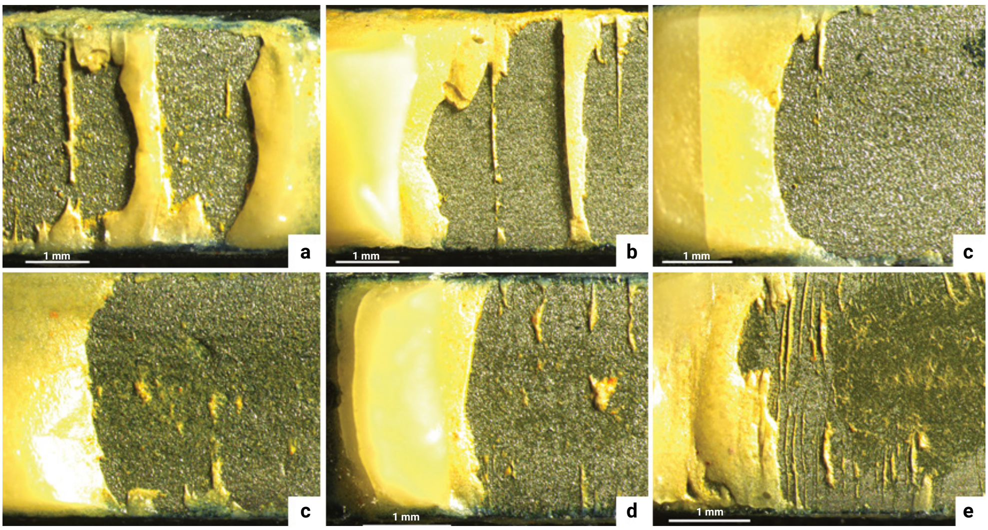

Figure 1. Aspect of the metal surface without welding: APA a) 250 µm, b) 100 µm and c) 50 µm. Aspect of the metal surface with TIG welding: APA c) 250 µm, d) 100 µm and e) 50 µm.

Although the conventional brazing technique is more used in dentistry, studies have demonstrated the superiority of tungsten inert gas (TIG) welding[15,16]. This process uses an electric arc formed between a non-consumable tungsten electrode and the part to be fused and applies an inert gas (argon or helium) to provide local protection to prevent oxidation[17-20]. In this type of welding, heating is concentrated and disorders and deformation are minimized; furthermore, there is an increase in corrosion resistance due to the lack of galvanic effects in the joint[17].

Although TIG welding is widely used in engineering, the equipment has been adapted to enable its use in dentistry. Therefore, it is an alternative in rehabilitation treatment with metal-ceramic restorations. However, there is still a lack of studies evaluating the adhesion of ceramics in areas that have been subjected to this type of welding, mainly with Co-Cr alloys.

The purpose of this study was to evaluate the bonding strength between areas in Co-Cr alloys that undergo TIG welding and APA using different sizes of Al_2O_3 particles.

Material and methods

A total of 90 patterns of thermopolymerizable acrylic resin (Jet, Artículos Odontológicos Clássico Ltda, São Paulo, SP, Brazil) were obtained with the following dimensions: 25 mm in length, 3 mm in width and 1 mm in thickness (n=60); and 50 mm in length, 3 mm in width and 1 mm in thickness (n=30).

The ends of the strips were joined using wax (Wax in sprue Kota, São Paulo, Brazil), and the feed conduits (Wax in sprue Kota, São Paulo-SP, Brazil) were positioned perpendicular to the standards (Silicone Ring OGP, São Paulo-SP, Brazil) for inclusion. A Nº 5 silicone ring was filled with coating material (Microfine 1700 Coat Talmax, Curitiba-PR, Brazil) at a ratio described by the manufacturer (90 g powder: 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 Equipment - Guarulhos – SP, Brazil) for 30 s.

The coating was placed in an electric oven (EDGCON 5P, Equipamentos e Controlles LTDA, São Carlos, SP, Brazil) at a temperature of 400°C for 30 min. Subsequently, the temperature was raised to 950°C, and maintained for 20 min. After this, the temperature was reduced, and the ring was removed (900°C for Co-Cr alloys).

Fifteen grams of Co-Cr alloy were distributed inside the ceramic crucible for the induction centrifugation system (Power Cast Red - EDG - São Carlos - SP - Brazil). The specifications of the alloy are listed in Table 1. After metal cooling, the strips were finished with polystyrene (Arotec, Cotia, SP, Brazil) Al_2O_3 sandpaper (120 grit; Aixa Abrasive, Norton Abrasive Ltd, São Paulo-SP, Brazil). The group allocations are listed in Table 2.

A single operator performed the entire welding process according to standardized methods. TIG welding was performed using TIG NTY 60C welding equipment (Kernit Indústria Mecatrônica Ltda, Indaiatuba, SP, Brazil). The apparatus was positioned perpendicular to the part to be welded. A grounding claw was attached to the part. The system was activated and argon flow was initiated, forming an oxygen-free region. An acrylic device containing a channel was used for accommodating the specimens, without any spaces between them[19].

Table 1. Mechanical, physical and thermal properties of the Co-Cr alloy (Fit Cast Talmax) available from the manufacturer.

Properties	Values
Expansion Coefficient	14.0 (25 ºC - 600 ºC)
Specific weight	8.2 (g/cc)
Stretching	2%
Elasticity	663Mpa
Resistance	549 Mpa
Fusion Interval	1360 ºC - 1410 ºC
Casting Temperature	1460 ºC

Table 2. Description of Groups.

Groups	Alloy	Welding / APA	Ceramics
G1(n = 10)	Co-Cr	Without welding / APA (250µm) - Control	Vita VM13
G2(n = 10)	Co-Cr	TIG / APA (250µm)- Control	Vita VM13
G3(n = 10)	Co-Cr	Without welding / APA (100µm)	Vita VM13
G4(n = 10)	Co-Cr	TIG / APA (100µm)	Vita VM13
G5(n = 10)	Co-Cr	Without welding / APA (50µm)	Vita VM13
G6(n = 10)	Co-Cr	TIG / APA (50µm)	Vita VM13

* APA: Airborne-particle abrasion

All groups were subjected to APA using Al_2O_3 (Bio-art aluminum oxide, São Carlos-SP, Brazil) for 10–15 s, at a pressure of 60 lbs/in^2 (Table 2). For the control groups, a particle size of 250 µm was used, as recommended by the manufacturer of the ceramics. In addition, all strips were placed on a vibrator with distilled water for waste removal.

An acrylic matrix was prepared to delimit the ceramic application area to 8 ± 0.1 mm in length, 3 ± 0.1 mm width and 1 ± 0.1 mm thickness. The ceramic, Vita VM13 (Vita Ceramics, Bad Säckingen- Baden-Württemberg, Germany) was applied to the center of the weld area on one side of the metal specimens. First, an opaque layer was applied, which was subjected to a firing cycle according to the manufacturer's protocol. Using the bounding matrix, dentin layers were applied to the established dimensions[21].

An evaluation of bond strength between the ceramic and metallic substrates was performed using a 3-point bending test, which used a 50 N load at a speed of 0.5 mm/min. All samples were evaluated in a test machine (Kratos Equipment, São Paulo, SP, Brazil) at the Dental Materials Laboratory in the Dental School of the Federal University of Pará, Brazil.

The flexural strength was calculated according to the following formula:

$$\sum = 3Pl$$

$$2bd^2$$

In which P is the maximum force (N), l is the distance between the supports (mm), b was the sample width (mm), d is the sample thickness (mm), and Σ is the flexural strength (MPa)[17].

The specimens were analyzed using a stereomicroscope (Leica M205A, Meyer Instruments, Houston, TX, USA; Collection of Paleontology, the Emilio Goeldi Museum, Belém, Pará, Brazil), at 30× magnification. The fractured areas of porcelain were classified as follows[4]: adhesive failure, when most of the ceramic had been released from the metal; cohesive failure, when the ceramic detached from the structure without exposing the metal; and mixed failure, when part of the ceramic was released from the metal and a part remained attached to it.

Flexural strength data (in MPa) were analyzed using two-way analysis of variance (factor 1: use of welding; factor 2: size of Al_2O_3 particle). The Tukey test was performed to compare mean values among the groups ($\alpha = 0.05$). Statistical analysis was performed using SPSS version 20.0 (IBM Corporation, Armonk, NY, USA). The level of statistical significance level was set at 5%.

Results

Mean values (Mpa) and standard deviation of flexural strength are summarized in Table 3. The analysis revealed a significant difference in the bond strength of ceramic between the groups that used TIG welding and those that did not, for all sizes of Al_2O_3 ($p < 0.01$). The best flexural strength results were observed in all groups without welding.

Table 3. Mean (MPa) and Standard Deviation of the flexural strength.

	Without TIG	TIG welding
APA 250μm	54.4 ± 4.07 Aa	41.7 ± 5.09 Bb
APA 100μm	49.5 ± 2.32 Aa	34.6 ± 2.38 B*
APA 50μm	44.7 ± 3.01 Aa	31.5 ± 2.44 Ba

* Different lowercase letters in columns and different uppercase letters in rows represent significant statistical differences. The presence of * indicates no difference compared to the other groups in the same column.

There was no statistical difference between the sizes of oxide particles among the groups without welding. However, there were significant differences between the TIG 250 μm and TIG 50 μm groups ($p < 0.05$), and the control group demonstrated better results. There were only mixed faults in all groups. The predominance of irregularities in the metal surface in the groups that underwent TIG welding (G2, G4 and G6), such as internal defects and depressions, were clearly evident.

Discussion

The primary requirement for success in metal-ceramic restorations is the effective attachment of the ceramic to the substructure of the metal alloy[22]. This bond depends directly on the formation of an oxide layer on the surface of the metal before firing the ceramic[4-6]. The control of this layer can be facilitated by APA using Al_2O_3, which also increases the area and the degree of wettability of the metal framework for the application of the ceramic[8,9].

Several sizes of Al_2O_3 particles have been used in the APA process in non-noble alloys. Reports have claimed, however, that this process may compromise the marginal integrity of the metal, and that damage is directly proportional to the size of the Al_2O_3 particle[23-25]. In a study comparing metal-ceramic adhesion in Co-Cr and Ni-Cr alloys, there was a better bond strength in specimens that used Al_2O_3 particles 110 µm in size[8].

In the present study, there were no significant statistical differences between the non-welded groups. A possible explanation could be that the time used (10-15 s) was not sufficient, given that in a recent study, 30 s increased surface roughness, which increased mechanical retention, which in turn is a significant factor for achieving better metal-ceramic bond strength[26]. APA with variation in time and distance could be a useful analysis in a future study.

Welding is used to solve problems of adaptation. This technique reduces faults during the fabrication of the metallic structure and provides uniform distribution of forces[27]. TIG welding has advantages over the conventional technique, such as lower heat production and the possibility of welding on the working model itself, thus reducing process time and failure rate[28].

TIG welding resulted in a significant difference between the groups blasted with 250-µm- and 50-µm-Al_2O_3 particles, with larger particles demonstrating greater resistance. These results are in agreement with those described by Galo et al.[29], who reported better results using 110-µm-Al_2O_3 particles without welding, while the lowest value was found in the laser group and blasted with 50-µm-particles. It is possible that blasting with smaller particles influences the thickness of the oxide layer of metal surface required for the bond strength between metal and ceramic with TIG welding, thus reducing flexural strength.

Another possibility is that blasting with 50-µm-particles does not result in an optimum variation in surface irregularities. Thus, particles this size are too small to promote complete filling with liquid ceramics in a metal framework and supplying effective mechanical joints[7].

The present study demonstrated better performance in the groups without welding compared to those with TIG welding. Differences in chemical and physical composition between the metallic alloys, the weld area, and the weld contributed to normalize the structure and may have caused this decrease in flexural strength. Previous studies have shown that this rapid solidification of the bound area could cause microstructural changes[12]. However, TIG welding has the advantage of using a minimum amount of heat, reducing the amount of free oxygen and, when compared with brazing, yields greater flexural strength [27].

The results of the present study are consistent with those reported by Mehdi and Ibrahim[30], who found significantly lower resistance for laser-welded groups (11.7 MPa) and brazing groups (10.4 MPa) compared with the control group (25.4 MPa); thus, welding negatively affected the metal-ceramic bond strength. However, it is necessary to investigate differences in the coefficients of thermal expansion between the materials, because a minimum difference between these values is required[30].

The nature of the fractures was mixed in all the samples. This was considered an adequate bond strength because higher resistance is evident when the fracture occurs inside the ceramic and not at the interface (i.e., adhesive failures)[31]. Although statistical results revealed the least resistance in the welded groups, no adhesive failures were observed, unlike a study using brazing and laser welding, in which adhesive failures predominated in the welded specimens[12]. Nevertheless, further studies using scanning electron microscopy are necessary, and it is important to note that this was a limitation of the present study.

Within the limitations of the present study, we conclude that APA using 250-μm-Al_2O_3 particles significantly increased the bond strength between metal and ceramic in TIG-welded specimens. However, the size of the Al_2O_3 particles exhibited no differences in the bond strength of ceramic in samples without the welding process. The welding process negatively interfered with the bond strength of ceramic to metal.

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DECLARATION OF CONFLICTING INTERESTS

The authors declares that there is no conflict of interest.

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