






Fit of metal-ceramic crowns: effect of coping fabrication method and veneering ceramic application

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Aim: To evaluate the influence of cobalt-chromium (Co-Cr) coping fabrication methods and ceramic application on the marginal and internal fit of metal-ceramic crowns. **Methods:** Co-Cr copings for metal-ceramic crowns were prepared by lost wax casting or CAD-CAM machining of sintered blocks. The fit was analyzed using the silicone replica technique at four assessment points: marginal gap (MG), axial wall (AW), axio-occlusal (AO) angle, and central occlusal (CO) wall. After the initial analysis, the copings were ceramic-veneered with the layering technique, and the fit was again determined. Data were statistically analyzed by paired and unpaired Student's-t test ($\alpha=0.05$). **Results:** Marginal and internal fit before ceramic application according to the coping manufacturing method showed significant differences only at CO ($p < 0.001$), with milled copings ($137.98 \pm 16.71 \mu\text{m}$) showing higher gap values than cast copings ($112.86 \pm 8.57 \mu\text{m}$). For cast copings, there were significant differences at MG (before $109.13 \pm 8.79 \mu\text{m}$; after $102.78 \pm 7.18 \mu\text{m}$) and CO (before $112.86 \pm 8.57 \mu\text{m}$; after $104.07 \pm 10.63 \mu\text{m}$) when comparing the fit before and after ceramic firing. For milled copings, there was significant difference only at AO (before $116.39 \pm 9.64 \mu\text{m}$; after $108.54 \pm 9.26 \mu\text{m}$). **Conclusion:** This study demonstrated that the coping fabrication method influenced the internal fit. Ceramic firing maintained or improved the fit of the metal-ceramic crowns. The marginal discrepancy of all restorations, before and after ceramic firing, can be considered clinically acceptable.

Keywords: Dental marginal adaptation. Crowns. Metal ceramic alloys. Ceramics.

Introduction

Metal-ceramic crowns are still commonly used for indirect single-unit restorations and fixed partial dentures^{1,2}, because they combine the strength of the metal infrastructure and the esthetics provided by the veneering ceramic³. Even with the increase in the clinical indications of all-ceramic restorations, metal-ceramic crowns are the treatment of choice for patients with parafunctional oral habits, mainly for the posterior region². It happens because of their high mechanical properties and predictability of long-term clinical outcomes⁴.

Marginal fit is a critical factor for the success of indirect restorations⁵. Poorly fit crowns may cause hypersensitivity, biofilm accumulation, gingivitis, periodontitis, and alveolar bone loss, which could eventually lead to tooth loss⁶⁻⁸. Indirect restorations with good marginal fit may reduce gingival inflammation and cement dissolution, which are among the most common causes for prosthetic failures, in addition, excellent internal fit promotes proper seating of the crown, compromising neither the margins nor the preparation⁹.

Among the methods used for the fabrication of metal copings, lost wax casting is the most widely used technique, both for noble and basic alloys, but the several steps necessary and the dependence on the ability of the technician can cause discrepancies in the marginal and internal fit of the final restoration¹⁰. Because of the challenges involved with the lost-wax technique, new technologies for the manufacture of metal copings have been introduced. The most commonly used methods include computer-aided design and computer-aided manufacturing (CAD-CAM) of pre-sintered or sintered metal blocks and additive techniques, such as selective laser melting¹⁰⁻¹³. These new technologies facilitate laboratory procedures, save time and may result in restorations with improved marginal and internal adaptation^{10,13}.

Different methods can be used for application of the veneering ceramic over metal copings. Conventional layering technique (also known as vibration-condensation) and heat-pressing are two of them¹⁴. In the layering technique, powder and modeling liquid are mixed and applied on the coping in a larger volume to compensate for the shrinkage of the ceramic material during sintering¹⁵. However, multiple applications and firing cycles until application of the ceramic is complete (at least three firing cycles, considering the dentin, enamel, and glaze) may interfere with marginal and internal fit. Moreover, the ceramicist's skills are important at this stage so that a consistent and uniform ceramic thickness is maintained during application¹⁶.

The evaluation of the marginal and internal fit of metal-ceramic crowns fabricated through different methods and the effect of ceramic firings may help clinicians choose the most appropriate fabrication method for indirect metal-ceramic restorations, preventing failures related to poor-fitted crowns, increasing the clinical longevity of the restorative treatments. Thus, the aim of this study was to assess the influence of Co-Cr coping fabrication methods and of ceramic veneer application on the marginal and internal fit of metal-ceramic crowns. The null hypotheses were

that: i) the Co-Cr coping fabrication method would not influence the marginal and internal fit of metal-ceramic crowns, and ii) the ceramic veneering application would not influence the marginal and internal fit of Co-Cr copings, regardless of coping fabrication method.

Materials and methods

A model for the preparation of a metal-ceramic crown in a lower molar was milled using CAD/CAM acrylic resin block (VIPI block, Pirassununga, SP, Brazil). The preparation was made by simulating supragingival circumferential chamfer finish line, 2.0-mm occlusal reduction, 1.5-mm axial reduction, axial convergence angle of 6°, and rounded internal line angles.

The master model was digitally scanned (Ceramill Map400, Amann Girrbach, Koblach, Austria) for the fabrication of twenty Co-Cr copings, with thickness of 0.5 mm at the margins and 0.8 mm at the axial and occlusal walls. Ten copings were obtained by lost wax casting fabricated with a Co-Cr alloy (Fit Cast Cobalt, Talmax, Curitiba, Brazil) with the following composition: 61% cobalt, 30% chromium, 5.9% molybdenum, <1% silicon, and <1% manganese. Other ten copings were subjected to CAD-CAM milling (CeraMill Motion, Amann Girrbach, Koblach, Austria) of sintered blocks (Ceramill Sintron, Amann Girrbach, Koblach, Austria) with the following composition: 66% cobalt, 30% chromium, 5% molybdenum, <1% silicon, <1% iron, and <1% manganese. Sample size was determined based on previous studies that also evaluated the marginal fit of metal-ceramic restorations before and after ceramic firing¹⁷⁻¹⁹.

The silicone replica technique was used to assess marginal and internal fit of the copings^{20,21}. The replicas were obtained i) after the fabrication of the copings and ii) after ceramic veneering. To produce the replica, each coping was filled with a light-body PVS material (Adsil Light Body, Coltène/Whaledent, Altstätten, Switzerland) and positioned on the master model. Firm finger pressure simulating a definitive cementation was applied and after 5 minutes the coping was removed from the master model. This procedure was practiced in a pilot study and has been previously reported in the literature¹⁹⁻²². To take out the light-body material from the coping and determine its thickness, which corresponds to the marginal and internal gap, a regular-body PVS material with contrasting color (Adsil Regular Body, Coltène/Whaledent, Altstätten, Switzerland) was placed into the coping to produce the replica. After polymerization, the replica was cut with a sharp scalpel blade in buccolingual and mesiodistal directions to obtain four cross-sections (Figure 1).

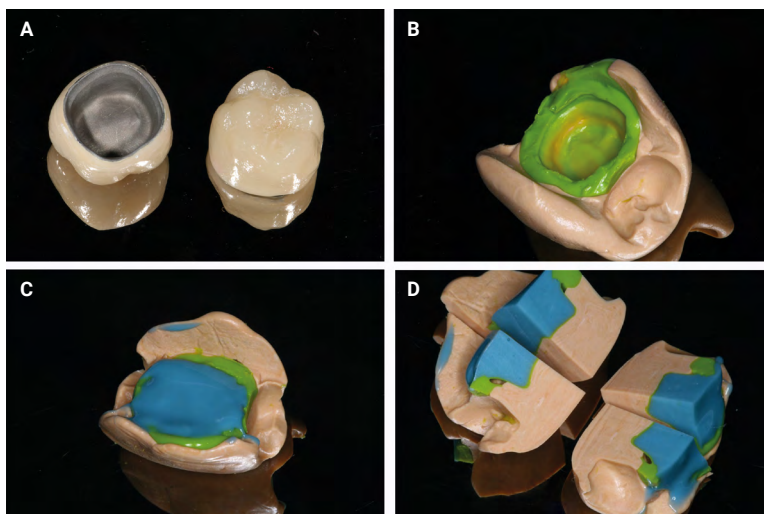


Figure 1. Silicone replica technique: A – Metal-ceramic crown; B – Light-body PVS material (in green), which corresponds to the marginal and internal gap; C – Regular-body PVS material with contrasting color placed into the coping; D – Cross-sections obtained after cutting the replica in buccolingual and mesiodistal directions.

The four cross-sections of each replica were placed on a scanner (C3180 HP Photosmart; HP) for digitization. The high-resolution images (1200 dpi) were saved as jpg files and a single operator determined the thickness of the light-body PVS material using an image analyzing software (ImageJ, U. S. National Institutes of Health, Bethesda, Maryland, USA). The following assessment points were evaluated in each of the sections: marginal gap (MG), axial wall (AW), axio-occlusal (AO) angle, and central occlusal (CO) wall^{20,21} (Figure 2). Four measurements of each of the points were made for each replica, and the mean was estimated for each point in each replica.

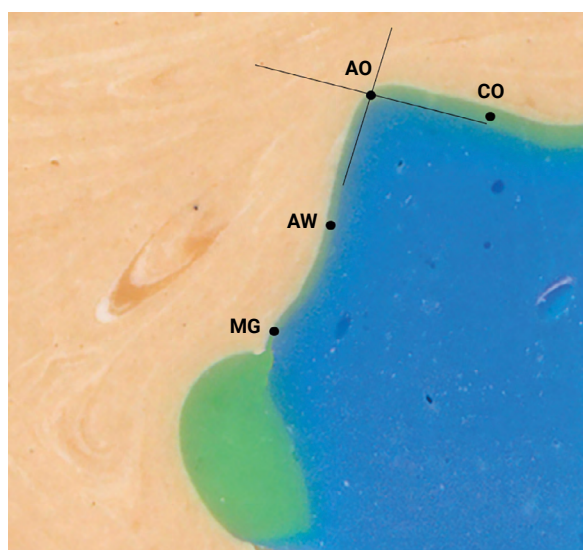


Figure 2. Light-body PVS replica showing the four assessment points.

After determining the marginal and internal fit of the copings (initial – before ceramic application), they were ceramic-veneered with the layering technique. The porcelain powder (HeraCeram, Heraeus-Kulzer, Hanau, Germany) was mixed with water and applied over the coping with a brush, and the excess water was wiped off with absorbent paper. Porcelain was applied in excess to compensate for the shrinkage observed after the porcelain was fired. The application was standardized using four firings (opaque layer firing, first firing for dentin, second firing for dentin, and glaze). All firings were performed in the same furnace for porcelain sintering (DEKEMA Austromat 624, Jensen Dental, North Haven, CT, USA).

Statistical analyses were performed individually for each assessment point. The fit before or after ceramic application, comparing cast versus milled copings, was assessed by Student's t-test. Paired Student's t-tests were used to evaluate the marginal and internal fit for each coping manufacturing method before and after ceramic veneering. All analyses were carried out at a significance level of 0.05.

Results

The means and standard deviations of the fit (before and after ceramic firing) according to the coping manufacturing method (casting or milling) for each assessment point are shown in Table 1. Considering the fit before ceramic firing, the statistical analysis revealed significant differences only at CO ($p < 0.001$), with milled copings ($137.98 \pm 16.71 \mu\text{m}$) showing higher gap values than cast copings ($112.86 \pm 8.57 \mu\text{m}$). MG ($p = 0.224$), AW ($p = 0.818$) and AO ($p = 0.112$) showed statistically similar values. Comparing the fit of cast versus milled copings after ceramic application, the statistical analysis revealed significant differences at AW ($p = 0.019$, higher gap for cast copings) and CO ($p < 0.001$, higher gap for milled copings). MG ($p = 0.225$) and AO ($p = 0.156$) showed statistically similar values.

Table 1. Means and standard deviations of marginal and internal fit (in μm) at the assessed points for cast and milled copings before and after ceramic veneering.

	MG		AW		AO		CO	
	Ceramic firing		Ceramic firing		Ceramic firing		Ceramic firing	
	Before	After	Before	After	Before	After	Before	After
Cast copings	109.13 \pm 8.79 ^{Ab}	102.78 \pm 7.18 ^{Aa}	107.43 \pm 10.63 ^{Aa}	104.48 \pm 7.31 ^{Ba}	107.77 \pm 13.15 ^{Aa}	100.24 \pm 15.11 ^{Aa}	112.86 \pm 8.57 ^{Ab}	104.07 \pm 10.63 ^{Aa}
Milled copings	104.18 \pm 8.80 ^{Aa}	97.94 \pm 9.78 ^{Aa}	106.06 \pm 14.90 ^{Aa}	93.25 \pm 11.70 ^{Aa}	116.39 \pm 9.64 ^{Ab}	108.54 \pm 9.26 ^{Aa}	137.98 \pm 16.71 ^{Ba}	127.65 \pm 9.82 ^{Ba}

For each point, in the columns, values followed by the same uppercase superscript letters are statistically similar when comparing cast x milled copings before or after ceramic application ($p > 0.05$).

For each point and coping fabrication method, in the lines, values followed by the same lower case superscript letters are statistically similar when comparing before and after ceramic application ($p > 0.05$).

For cast copings, there were statistically significant differences at MG (before $109.13 \pm 8.79 \mu\text{m}$; after $102.78 \pm 7.18 \mu\text{m}$; $p = 0.048$) and CO (before $112.86 \pm 8.57 \mu\text{m}$; after $104.07 \pm 10.63 \mu\text{m}$; $p = 0.016$) when comparing the fit before and after ceramic firing. For AW and AO, no statistically significant difference was observed between the copings before and after ceramic veneering. For milled copings, there was statistically

significant difference only at AO (before $116.39 \pm 9.64 \mu\text{m}$; after $108.54 \pm 9.26 \mu\text{m}$; $p = 0.049$). It is important to note that, when statistically significant differences were observed, lower gap values were obtained always after ceramic veneering.

Discussion

In this study, the first null hypothesis, that there would be no difference in marginal and internal fit of Co-Cr copings for the different techniques used (casting and CAD-CAM milling of sintered blocks), was accepted for marginal fit and rejected for internal fit. CO assessment point of CAD-CAM-milled copings showed poorer internal fit than cast copings.

The findings of the present study are in accordance with previous ones in the literature. Han et al.²³ investigated the effect of the manufacturing method (casting or CAD-CAM milling) on the marginal and internal fit of titanium crowns, and showed that cast crowns had better marginal and internal fit both at the margin and in the occlusal area than did CAD-CAM-milled crowns. Among the different methods for the fabrication of metal copings, casting is more likely to have poor fit because of the larger number of steps involved¹³, which was not confirmed in the present study. Our results showed that the marginal fit of both copings was similar, but internal fit was better for cast copings. The higher values obtained for the occlusal surface when compared with the axial wall are also described in previous studies^{13,20,21,24}, despite the fact that milled copings are believed to have lower marginal discrepancies, since their fabrication has fewer steps. According to the literature, cement film thickness varies considerably, but most authors describe $120 \mu\text{m}$ as the clinically acceptable maximum thickness for a long-term good prognosis²⁵. In most studies, thickness is close to $120 \mu\text{m}$, but there are some questions about whether this value is still valid given the new materials and fabrication methods now commercially available.

At the axio-occlusal angle and on the occlusal surface, the poorer fit of milled copings as compared to cast copings can be explained by the quality of data acquisition and processing in CAD-CAM²⁶. Poorer internal fit may result from round edges produced by the finite resolution of the CAD-CAM imaging system and difficulty in scanning the axio-occlusal angle. Fit at AO is influenced by the image captured by the scanner and reconstruction of this angle by the software program, as the light reflected during the reading procedure is stronger than in flat regions²⁷. Moreover, poor preparation makes this area more irregular, and could also lead to poor fit. Overshoot, a phenomenon that simulates virtual peak values close to the edges, could also cause larger internal discrepancies^{28,29}. Similar findings were also previously reported³⁰, showing significant lower gap values in axio-occlusal and occlusal regions for Co-Cr cast copings when compared to Co-Cr milled copings.

It is also important to note that the compositions of the metal alloys used in the present study are very similar. The main difference between the alloys is in the percentage of cobalt (61% and 65%). In general, the composition of the alloys may vary from one commercial brand to another, and even more when different manufacturing methods (casting and CAD/CAM milling) are used. However, it has been reported that the weight percentage of cobalt for Co-Cr alloys usually ranges from 53 and 68%³¹. Thus, the two alloys used in the present study have the percentage of cobalt within that range.

The second null hypothesis, that the ceramic veneering application would not influence the marginal and internal fit of Co-Cr copings, was accepted for cast and milled copings. With regard to marginal and internal fit before and after ceramic application, higher gap values were observed always in copings before ceramic firing. The changes in fit for cast copings corresponded to -5.82% at MG and to -7.78% at CO. In milled copings, the change occurred only at AO, exhibiting a rate of -6.75% after ceramic application. In the present study, when significant differences were observed, lower gap values were obtained after ceramic veneering. For the marginal fit, this result was also reported by Real-Voltas et al. (2017), who attributed this result to the fact that the porcelain firing improved the mismatch of the metal coping³².

Several studies demonstrated that the porcelain veneering application could change the fit of crowns and cause distortion in the metal substructure^{17,33,34}. One of the possible explanations for this effect is the development of compressive forces on metal coping as a consequence of the sintering contraction that occurs in the veneering porcelain during firing³⁵. Another study also indicated that the marginal fit of metal copings can be altered after porcelain veneering at different stages³⁶. Interestingly, the largest marginal discrepancies occurred in basic alloys and after opaque layer firing.

The present study assessed marginal and internal fit using the silicone replica technique. This technique has produced reliable outcomes and has been reported to be as accurate as the cross-section of the die and restoration for later direct microscopic evaluation of the fit³⁷. Its major advantages include the ease with which it is performed and its low costs³⁸, in addition to the simulation of finger pressure at the time of luting of the crowns over the tooth preparation. Lately, micro-CT imaging has also been used to assess the marginal and internal fit of crowns and fixed partial dentures^{11,28,39}. Both non-destructive methods are considered effective to evaluate the adaptation of indirect restorations^{20,24}.

Metal-ceramic restorations may show some distortions in the different stages of coping fabrication and of ceramic firing, resulting in marginal and internal discrepancies. The main factors could be the difference in the coefficient of thermal expansion between the metal coping and the porcelain, the coping fabrication method, and sintering shrinkage. Therefore, studies that assess the change in the fit of copings by different methods and after application of veneering ceramic may be better at preventing remarkable and clinically unacceptable poor fit. Large marginal discrepancies may be harmful to both abutment teeth and periodontal tissues. Despite the significant increase in the number of all-ceramic crowns and fixed partial dentures, metal-ceramic crowns still play an important role in oral rehabilitation and may be indicated and used in clinical practice for a long time, as they have a high rate of clinical success and proven longevity.

The limitations of this study include the use of only two Co-Cr alloys for metal-ceramic crowns. Other base metal alloys, such as Ni-Cr and Ti-based alloys were not investigated in the present study. Also, the marginal and internal fit of single crowns was investigated and the results may not be valid for multiple fixed partial dentures. The application of finger pressure to obtain the silicone replica, despite clinically significant, could have affected the reproducibility of the measurements. Finally, since the adaptation of the crowns was evaluated under *in vitro* conditions, the results may not be directly extrapolated to the clinical practice.

In conclusion, the coping fabrication method influenced internal fit. Ceramic application maintained or improved the fit of the metal-ceramic crowns. The marginal discrepancy of all restorations, before and after ceramic firing, can be considered clinically acceptable.

Data availability

Datasets related to this article will be available upon request to the corresponding author.

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