BJOS Brazilian Journal of Oral Sciences

Original Article

Volume 21
2022
e225136

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

Patrícia Valéria Manozzo Kunz[1], Gabriela Andrade Serpa[1], Leonardo Fernandes da Cunha[2], Gisele Maria Correr[1], Carla Castiglia Gonzaga[1,*]

[1] School of Health Sciences, Graduate Program in Dentistry, Positivo University, Curitiba, Brazil.

[2] Department of Dentistry, School of Health Sciences, University of Brasilia, Brasilia, Brazil.

Corresponding author:
Carla Castiglia Gonzaga
Universidade Positivo
Rua Prof. Pedro Viriato Parigot de Souza, 5300 – 81280-330 – Curitiba – PR – Brasil
Phone: (5541) 3317-3180
Fax: (5541) 3317-3082
E-mail: carlacgonzaga2@gmail.com

Editor: Dr Altair A. Del Bel Cury

Received: March 30, 2021
Accepted: June 15, 2021

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 (α=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±16.71 μm) showing higher gap values than cast copings (112.86±8.57 μm). For cast copings, there were significant differences at MG (before 109.13±8.79 μm; after 102.78±7.18 μm) and CO (before 112.86±8.57 μm; after 104.07±10.63 μm) when comparing the fit before and after ceramic firing. For milled copings, there was significant difference only at AO (before 116.39±9.64 μm; after 108.54±9.26 μm). **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 ceramic[3]. 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 region[2]. It happens because of their high mechanical properties and predictability of long-term clinical outcomes[4].

Marginal fit is a critical factor for the success of indirect restorations[5]. Poorly fit crowns may cause hypersensitivity, biofilm accumulation, gingivitis, periodontitis, and alveolar bone loss, which could eventually lead to tooth loss[6-8]. Indirect restorations with good marginal fit may reduce gingival inflammation and cement dissolution, which are among the most common causes for prosthetic failures, in addiction, excellent internal fit promotes proper seating of the crown, compromising neither the margins nor the preparation[9].

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 restoration[10]. 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 melting[10-13]. 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 them[14]. 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 sintering[15]. 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 application[16].

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^{o}, 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 firing[17-19].

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 literature[19-22]. 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).

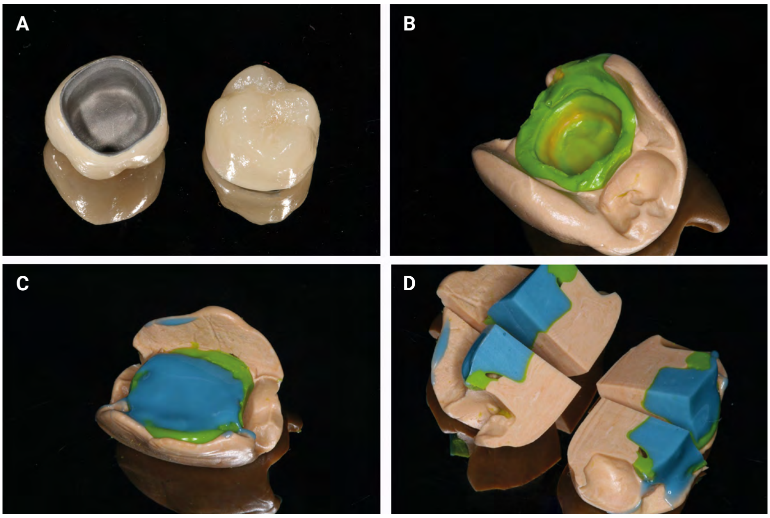

Figure 1. Silicone replica technique: A – Metal-ceramic crown; B – Light-body PVS material (in green), which corresponds to the marginal and internal gap; C – Regular-body PVS material with contrasting color placed into the coping; D – Cross-sections obtained after cutting the replica in buccolingual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

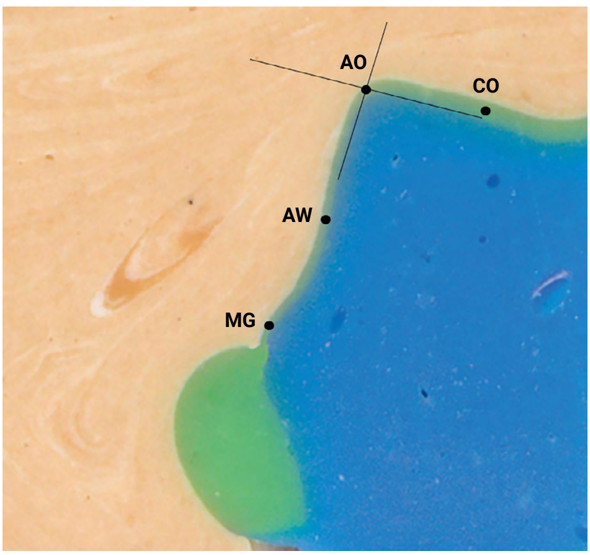

Figure 2. Light-body PVS replica showing the four assessment points.

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 ± 16.71 μm) showing higher gap values than cast copings (112.86 ± 8.57 μm). 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 ± 8.79 ^{Ab}	102.78 ± 7.18 ^{Aa}	107.43 ± 10.63 ^{Aa}	104.48 ± 7.31 ^{Ba}	107.77 ± 13.15 ^{Aa}	100.24 ± 15.11 ^{Aa}	112.86 ± 8.57 ^{Ab}	104.07 ± 10.63 ^{Aa}
Milled copings	104.18 ± 8.80 ^{Aa}	97.94 ± 9.78 ^{Aa}	106.06 ± 14.90 ^{Aa}	93.25 ± 11.70 ^{Aa}	116.39 ± 9.64 ^{Ab}	108.54 ± 9.26 ^{Aa}	137.98 ± 16.71 ^{Ba}	127.65 ± 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 ± 8.79 μm; after 102.78 ± 7.18 μm; $p = 0.048$) and CO (before 112.86 ± 8.57 μm; after 104.07 ± 10.63 μm; $p = 0.016$) 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 ± 9.64 μm; after 108.54 ± 9.26 μm; 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 involved[13], 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 μm as the clinically acceptable maximum thickness for a long-term good prognosis[25]. In most studies, thickness is close to 120 μm, 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-CAM[26]. 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 regions[27]. 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 reported[30], 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 coping[32].

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 firing[35]. Another study also indicated that the marginal fit of metal copings can be altered after porcelain veneering at different stages[36]. 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 fit[37]. Its major advantages include the ease with which it is performed and its low costs[38], 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.

References

1. Huang Z, Zhang L, Zhu J, Zhang X. Clinical marginal and internal fit of metal ceramic crowns fabricated with a selective laser melting technology. J Prosthet Dent. 2015 Jun;113(6):623-7. doi: 10.1016/j.prosdent.2014.10.012.
2. Makhija SK, Lawson NC, Gilbert GH, Litaker MS, McClelland JA, Louis DR, et al. Dentist material selection for single-unit crowns: Findings from the National Dental Practice-Based Research Network. J Dent. 2016 Dec;55:40-7. doi: 10.1016/j.jdent.2016.09.010.
3. Sola-Ruiz MF, Agustin-Panadero R, Campos-Estelles C, Labaig-Rueda C. Post-fatigue fracture resistance of metal core crowns: press-on metal ceramic versus a conventional veneering system. J Clin Exp Dent. 2015 Apr;7(2):e278-83. doi: 10.4317/jced.52267.
4. Reitemeier B, Hansel K, Kastner C, Weber A, Walter MH. A prospective 10-year study of metal ceramic single crowns and fixed dental prosthesis retainers in private practice settings. J Prosthet Dent. 2013 Mar;109(3):149-55. doi: 10.1016/S0022-3913(13)60034-7.
5. Denissen H, Dozic A, van der Zel J, van Waas M. Marginal fit and short-term clinical performance of porcelain-veneered CICERO, CEREC, and Procera onlays. J Prosthet Dent. 2000 Nov;84(5):506-13. doi: 10.1067/mpr.2000.110258.
6. Della Bona A, Kelly JR. The clinical success of all-ceramic restorations. J Am Dent Assoc. 2008 Sep;139 Suppl:8S-13S. doi: 10.14219/jada.archive.2008.0361.
7. Knoernschild KL, Campbell SD. Periodontal tissue responses after insertion of artificial crowns and fixed partial dentures. J Prosthet Dent. 2000 Nov;84(5):492-8. doi: 10.1067/mpr.2000.110262.
8. Lang NP, Kiel RA, Anderhalden K. Clinical and microbiological effects of subgingival restorations with overhanging or clinically perfect margins. J Clin Periodontol. 1983 Nov;10(6):563-78. doi: 10.1111/j.1600-051x.1983.tb01295.x.
9. Colpani JT, Borba M, Della Bona A. Evaluation of marginal and internal fit of ceramic crown copings. Dent Mater. 2013 Feb;29(2):174-80. doi: 10.1016/j.dental.2012.10.012.
10. Kane LM, Chronaios D, Sierraalta M, George FM. Marginal and internal adaptation of milled cobalt-chromium copings. J Prosthet Dent. 2015 Nov;114(5):680-5. doi: 10.1016/j.prosdent.2015.04.020.
11. Kim EH, Lee DH, Kwon SM, Kwon TY. A microcomputed tomography evaluation of the marginal fit of cobalt-chromium alloy copings fabricated by new manufacturing techniques and alloy systems. J Prosthet Dent. 2017 Mar;117(3):393-9. doi: 10.1016/j.prosdent.2016.08.002.
12. Quante K, Ludwig K, Kern M. Marginal and internal fit of metal-ceramic crowns fabricated with a new laser melting technology. Dent Mater. 2008 Oct;24(10):1311-5. doi: 10.1016/j.dental.2008.02.011.
13. Tamac E, Toksavul S, Toman M. Clinical marginal and internal adaptation of CAD/CAM milling, laser sintering, and cast metal ceramic crowns. J Prosthet Dent. 2014 Oct;112(4):909-13. doi: 10.1016/j.prosdent.2013.12.020.

14. Goldin EB, Boyd NW, 3rd, Goldstein GR, Hittelman EL, Thompson VP. Marginal fit of leucite-glass pressable ceramic restorations and ceramic-pressed-to-metal restorations. J Prosthet Dent. 2005 Feb;93(2):143-7. doi: 10.1016/j.prosdent.2004.10.023.

15. Holden JE, Goldstein GR, Hittelman EL, Clark EA. Comparison of the marginal fit of pressable ceramic to metal ceramic restorations. J Prosthodont. 2009 Dec;18(8):645-8. doi: 10.1111/j.1532-849X.2009.00497.x.

16. Bonfante EA, da Silva NR, Coelho PG, Bayardo-González DE, Thompson VP, Bonfante G. Effect of framework design on crown failure. Eur J Oral Sci. 2009 Apr;117(2):194-9. doi: 10.1111/j.1600-0722.2008.00608.x.

17. Ates SM, Yesil Duymus Z, Caglar I, Hologlu B. The effect of veneering on the marginal fit of CAD/CAM-generated, copy-milled, and cast metal copings. Clin Oral Investig. 2017 Nov;21(8):2553-60. doi: 10.1007/s00784-017-2054-x.

18. Hong MH, Min BK, Lee DH, Kwon TY. Marginal fit of metal-ceramic crowns fabricated by using a casting and two selective laser melting processes before and after ceramic firing. J Prosthet Dent. 2019 Nov;122(5):475-81. doi: 10.1016/j.prosdent.2019.03.002.

19. Kocaagaoglu H, Albayrak H, Kilinc HI, Gumus HO. Effect of repeated ceramic firings on the marginal and internal adaptation of metal-ceramic restorations fabricated with different CAD-CAM technologies. J Prosthet Dent. 2017 Nov;118(5):672-7. doi: 10.1016/j.prosdent.2016.11.020.

20. Cunali RS, Saab RC, Correr GM, Cunha LFD, Ornaghi BP, Ritter AV, et al. Marginal and internal adaptation of zirconia crowns: a comparative study of assessment methods. Braz Dent J. 2017 Jul-Aug;28(4):467-73. doi: 10.1590/0103-6440201601531.

21. Pedroche LO, Bernardes SR, Leão MP, Kintopp CC, Correr GM, Ornaghi BP, et al. Marginal and internal fit of zirconia copings obtained using different digital scanning methods. Braz Oral Res. 2016 Oct 10;30(1):e113. doi: 10.1590/1807-3107BOR-2016.vol30.0113.

22. Ogunc A, Yildirim Avcu G. Effect of repeated firings on the marginal and internal adaptation of implant-supported metal-ceramic restorations fabricated with different thicknesses and fabrication methods. J Prosthet Dent. 2021 Mar;125(3):504.e1-504.e6. doi: 10.1016/j.prosdent.2020.10.021.

23. Han HS, Yang HS, Lim HP, Park YJ. Marginal accuracy and internal fit of machine-milled and cast titanium crowns. J Prosthet Dent. 2011 Sep;106(3):191-7. doi: 10.1016/S0022-3913(11)60120-0.

24. Ram SM, Ranadive NN, Nadgere JB. Microcomputed tomography a noninvasive method to evaluate the fit of a restoration as compared to conventional replica technique. J Indian Prosthodont Soc. 2019;19(3):233-9. doi: 10.4103/jips.jips_71_19.

25. McLean JW, von Fraunhofer JA. The estimation of cement film thickness by an in vivo technique. Br Dent J. 1971 Aug 3;131(3):107-11. doi: 10.1038/sj.bdj.4802708.

26. Beuer F, Naumann M, Gernet W, Sorensen JA. Precision of fit: zirconia three-unit fixed dental prostheses. Clin Oral Investig. 2009 Sep;13(3):343-9. doi: 10.1007/s00784-008-0224-6.

27. Gaintantzopoulou MD, El-Damanhoury HM. Effect of preparation depth on the marginal and internal adaptation of computer-aided design/computer-assisted manufacture endocrowns. Oper Dent. 2016;41(6):607-16. doi: 10.2341/15-146-L.

28. Borba M, Cesar PF, Griggs JA, Della Bona A. Adaptation of all-ceramic fixed partial dentures. Dent Mater. 2011 Nov;27(11):1119-26. doi: 10.1016/j.dental.2011.08.004.

29. Reich S, Uhlen S, Gozdowski S, Lohbauer U. Measurement of cement thickness under lithium disilicate crowns using an impression material technique. Clin Oral Investig. 2011 Aug;15(4):521-6. doi: 10.1007/s00784-010-0414-x.

30. Gurel K, Toksavul S, Toman M, Tamac E. In vitro marginal and internal adaptation of metal-ceramic crowns with cobalt-chrome and titanium framework fabricated with CAD/CAM and casting technique. Niger J Clin Pract. 2019 Jun;22(6):812-6. doi: 10.4103/njcp.njcp_570_18.

31. Roberts HW, Berzins DW, Moore BK, Charlton DG. Metal-ceramic alloys in dentistry: a review. J Prosthodont. 2009 Feb;18(2):188-94. doi: 10.1111/j.1532-849X.2008.00377.x.

32. Real-Voltas F, Romano-Cardozo E, Figueras-Alvarez O, Brufau-de Barbera M, Cabratosa-Termes J. Comparison of the marginal fit of cobalt-chromium metal-ceramic crowns fabricated by CAD/CAM techniques and conventional methods at three production stages. Int J Prosthodont. 2017;30(3):304-5. doi: 10.11607/ijp.5038.

33. Gemalmaz D, Alkumru HN. Marginal fit changes during porcelain firing cycles. J Prosthet Dent. 1995 Jan;73(1):49-54. doi: 10.1016/s0022-3913(05)80272-0.

34. Regish KM, Sharma D, Prithviraj DR, Nair A, Raghavan R. Evaluation and comparison of the internal fit and marginal accuracy of base metal (nickelchromium) and zirconia copings before and after ceramic veneering: a sem study. Eur J Prosthodont Restor Dent. 2013 Mar;21(1):44-8.

35. Weaver JD, Johnson GH, Bales DJ. Marginal adaptation of castable ceramic crowns. J Prosthet Dent. 1991 Dec;66(6):747-53. doi: 10.1016/0022-3913(91)90408-o.

36. Shokry TE, Attia M, Mosleh I, Elhosary M, Hamza T, Shen C. Effect of metal selection and porcelain firing on the marginal accuracy of titanium-based metal ceramic restorations. J Prosthet Dent. 2010 Jan;103(1):45-52. doi: 10.1016/S0022-3913(09)60216-X.

37. Rahme HY, Tehini GE, Adib SM, Ardo AS, Rifai KT. In vitro evaluation of the "replica technique" in the measurement of the fit of Procera crowns. J Contemp Dent Pract. 2008 Feb;9(2):25-32.

38. An S, Kim S, Choi H, Lee JH, Moon HS. Evaluating the marginal fit of zirconia copings with digital impressions with an intraoral digital scanner. J Prosthet Dent. 2014 Nov;112(5):1171-5. doi: 10.1016/j.prosdent.2013.12.024.

39. Pimenta MA, Frasca LC, Lopes R, Rivaldo E. Evaluation of marginal and internal fit of ceramic and metallic crown copings using x-ray microtomography (micro-CT) technology. J Prosthet Dent. 2015 Aug;114(2):223-8. doi: 10.1016/j.prosdent.2015.02.002.