MARGINAL AND INTERNAL FIT EVALUATION OF METAL COPINGS FABRICATED BY SELECTIVE LASER SINTERING AND CAD/CAM MILLING TECHNIQUES: IN-VITRO STUDY

Shimaa H.Abdelhafiz[1*] BDS, Sanaa H.Abdelkader[2] PHD, Amir S.Azer[3] PHD

ABSTRACT

INTRODUCTION: Metal-ceramic restorations are still commonly used in dentistry. The success of these restorations depends mainly on the marginal integrity and the internal fit which in turn is affected by the technique of fabrication.

OBJECTIVES: Comparing the marginal and internal fit of metal copings manufactured using three different techniques.

MATERIALS AND METHODS: A metal master die simulating a maxillary first molar preparation was fabricated. Thirty Vinyl poly siloxane impressions were prepared for the master die and poured to obtain 30 epoxy resin dies. The epoxy dies were allocated at random to 3 groups (n=10) following the method of metal copings fabrication. Group I: selective laser sintering technique (additive technique), group II: CAD-CAM milling technique (subtractive technique), group III: lost wax technique (control group). The marginal and internal fit was evaluated by the silicone replica technique. The data were analyzed by One Way ANOVA followed by multiple pairwise comparisons using Bonferroni adjustment.

RESULTS: Group II had a significantly larger internal gap (33.60 μm) compared to group I (30.15 μm) and group III (27.83 μm) (P=0.03). No significant difference was found in the marginal fit.

CONCLUSIONS: Although Metal copings produced by the lost wax technique showed the best adaptation, all tested techniques resulted in clinically acceptable fit values.

KEYWORDS: Marginal fit, internal fit, selective laser sintering, and CAD-CAM.

RUNNING TITLE: Marginal and internal fit of metal copings made by different techniques.

1- Demonstrator of Fixed Prosthodontics, Conservative Department, Faculty of Dentistry, Alexandria University, Alexandria, Egypt.
2- Professor of Fixed Prosthodontics, Conservative Department, Faculty of Dentistry, Alexandria University, Alexandria, Egypt.
3- Associate professor of Fixed Prosthodontics, Conservative Department, Faculty of Dentistry, Alexandria University, Alexandria, Egypt.

Corresponding author:
Email: shimaa.rizk@alexu.edu.eg

INTRODUCTION

Despite the trend for metal-free restorations in contemporary dentistry, ceramo-metal restorations appear to be the gold standard owing to their outstanding mechanical properties, clinical efficiency, and suitable costs in addition to easy cementation procedure, and acceptable esthetics (1, 2). The conventional lost-wax technique is still widely used for manufacturing ceramo-metal restorations despite of the problems related to it (3-6).

Recently, various technological methods; which are more efficient and easier, such as computer-aided design (CAD) / computer-aided manufacturing (CAM) are used replacing the conventional lost-wax method (7-11).

The CAD-CAM systems in dentistry have been categorized as subtractive and additive approaches. The subtractive method uses block-shaped materials for prostheses fabrication by milling with cutting rotary instruments (5). Along with the CAD/CAM milling (subtractive method), a model change in the process of the metal coping manufacturing has come into life with the introduction of 3D printing technology (additive method) to avoid wasting of materials during the milling procedure (12). To create metal structures, 3D printers can be either indirectly used in burnout resins or waxes by means of a lost wax process or directly in alloys of metal (12). The direct 3D printing of metal alloys - known as selective laser sintering of metal alloys (SLS) - allows the removal of the main lost-wax method drawbacks: the casting shrinkage, simple manufacturing of complex forms, an automated device service, and saving time due to removal of wax pattern construction process, investing, burning, and casting work (13).

The SLS additive manufacturing process, which requires the use of powder-based materials to produce metal structures, enables particle precursors to be consolidated using a high-power laser (1-3).

Marginal inaccuracy is the most common cause of the failure of restorations (14). Thus, regardless of any manufacturing methods, the marginal and internal fit of the restoration is of primary value for its performance and longevity (15). Poor marginal or internal fit are faced with biological problems rather than mechanical ones (4, 8), causing plaque retention can result in marginal gingival inflammation, gingival recession, and secondary caries forming under the crown margins (9).

The optimally acceptable gap dimensions should be established before evaluating such parameters. However, there is no agreement about the marginal and internal discrepancies clinically reasonable limits. The marginal gap of about 25 - 40 micron was proposed as a clinical objective in line with the American Dental Association (ADA) Specification number eight (16). Sulaiman et al (17) claimed that an appropriate gap for clinical use is 100 µm, while the maximum for clinical use is 120 µm, according to McLean and von Fraunhofer (18). Even a gap of 200–300 µm is tolerable, Moldovan et al (19) reported. Nevertheless, many researchers and clinicians consider that the 120 µm value proposed by McLean and von Fraunhofer is the acceptable threshold clinically. Our goal is having the minimal marginal and internal gap that also enables the restoration to be properly seated.

Therefore, the aim of this study was to assess the marginal and internal fit of metal copings made by SLS compared to ones made by CAD-CAM milling using the lost-wax technique as a control. The null hypothesis was that the marginal and internal fit for metal copings made by either SLS, milling, or by lost wax technique would not be significantly different.

MATERIAL AND METHODS

The sample size (n=10) was calculated using preliminary tests with a power analysis to present statistical significance (α= 0.05) at 80 percent power (6). A specially designed Nickel- Chromium die was made by the lost wax method, to simulate the maxillary first molar tooth prepared to get porcelain fused to metal (PFM) crown. The metal die dimensions at the cervical level were 6 mm height, 8 mm faciolingual, 6 mm mesiodistal, 1 mm circumferential chamfer finish line, and 8-degree axial wall taper. All axial to occlusal surface transitions were rounded, and all prepared surfaces were smooth (Fig. 1A).

Thirty negative replicas from the prepared master die using vinylpoly siloxane duplicating content were produced and filled with epoxy resin material following the recommendations of the manufacturer, to get thirty identical replicas for the metal die, the reproduced dies were then softly polished (Fig. 1B).

The dies were scanned using KaVo ARCTICA® AutoScan (Fig. 1C), then copings were designed using the KaVo Everest multiCAD ® software with the following settings: the coping thickness was set half a mm and the die spacer thickness to 50 micron half a mm away from the margin and the design was then preserved in file format of stereolithography (STL) to be used for coping fabrication of the three test groups to be standardized (Fig. 2).

For the SLS Group, Co-Cr-Mo alloy powder (wirobound ® c+ BEGO) coping specimens were used to melt a controlled alloy powder deposit using the saved STL file and SISMA MYSINT 3D METAL PRINTING system with a high-precise high-energy laser (fiber laser of about 200 w). The laser sintering system worked by sintering the incremental layer of 20-micron thick Co-Cr alloy powder at a rate of 1.6 mm^3/s on a movable base, which then descend to a pre-set layer thickness, depositing a new alloy powder laminate and melting the next layer. Continued this procedure layer by layer pending 10 metal copings were completed.

The milling group specimens were fabricated by milling the coping from MAGNUM SPLENDIDUM type 4 MESA (Co-Cr) alloy disc by KaVo Everst CAD-CAM system using the same design saved on the STL file after Nesting was done. Connectors' positions, that connected the coping to the disc during milling, were adjusted to be on a smooth surface, not containing fine details away from the margins. After the coping was milled, it was separated from the remaining of the disc using a straight fissure bur mounted on a straight hand-piece, and smooth surfaces were attained.

In the casting group, ten resin patterns were fabricated from Everest C-Cast blanks using the same STL file by the KaVo Everst milling machine. Each pattern was sprued, invested using investment material (Bella vest® SH -BEGO), and cast by FORNAX T BEGO Induction Casting machine following the manufacturer’s instructions from Co-Cr alloy (*Wirobond® – SG (BEGO).*

No additional internal adjustment for all the test specimens was performed, any coping showed seating discrepancy was excluded from the specimens and remade.

All the copings were air abraded using 110-micron Al_2O_3 particles at a 0.3 MP pressure then were steam-cleaned, dried, and analyses were performed using the silicone replica method for marginal and internal fit assessment.

Each coping was filled by the light body silicone material (Express™ Light Body, Fast Set, 3M ESPE) and seated onto its die under 5 Kg (50 N) occlusal force by using a specially built loading system. The coping was removed from the die after a complete five-minute polymerization of the light-body silicone material, and the silicone replica was then stabilized by filling the coping completely with contrasting color, medium body silicone material (Express™, 3M ESPE).

The silicone replica was separated from the coping after complete polymerization and sliced using a sharp razor blade both in mesiodistal and buccolingual lines, resulting in 4 parts to be measured for each sample. For standardized sectioning, the middle edge of the replica surfaces has been marked before cutting.

Replica film thickness was examined using a regularly calibrated light microscope (SZ1145TR Olympus, Japan 1990) at ×18 optical magnification and a digital camera (X-CAM 1080 PHB, ToupCam Japan 2018) that was connected to computer software (Toup view version 3.7). The following four landmarks were assessed for each cross-section (20) (Fig. 3):

Marginal discrepancy (MD): The 2D vertical marginal discrepancy measured from the coping, to the margin of the preparation.

Mid-occlusal gap (MO): The perpendicular distance between the center of the occlsual surface of the die and the internal surface of the crown.

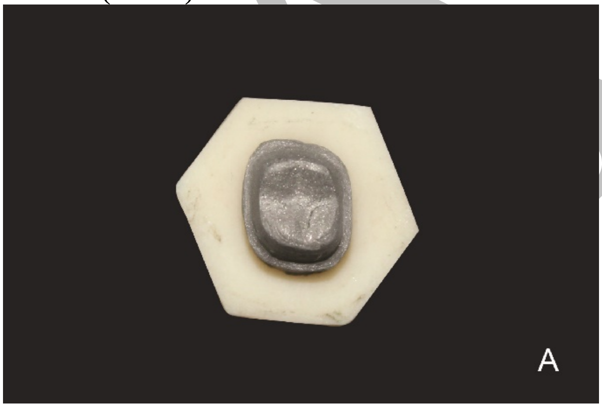
Axio-occlusal gap (AO): The perpendicular distance between the axio-occlusal line angle of the die and the internal surface of the crown.

Mid-axial gap (MA): The perpendicular distance between the middle of the axial surface of the die and the internal surface of the crown.

All sample measurements were carried out by one examiner. A total of 8 measurements were obtained by the examiner per each side (buccal, lingual, mesial, and distal) resulting in 320 measurements in 10 samples for each of the three comparative groups (Fig. 4).

statistical analysis

Normality was checked for all variables using descriptive statistics, plots, and normality tests. All variables showed normal distribution, so means and standard deviations (SD) were calculated. A comparison of the 3 groups was done with One Way ANOVA followed by multiple pairwise comparisons using Bonferroni adjustment. Significance was set at P <0.05. Data were analyzed using IBM SPSS statistical software (ver. 25).



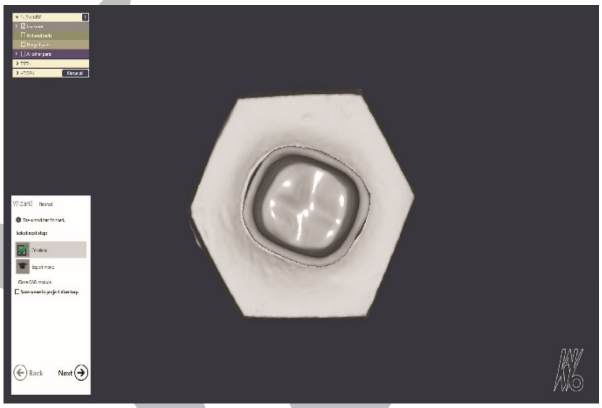


Fig. 1: showing the working die stages during the study.
A: Metal Master die of prepared maxillary first molar.
B: Duplicated epoxy resin dies.
C: The virtual die.

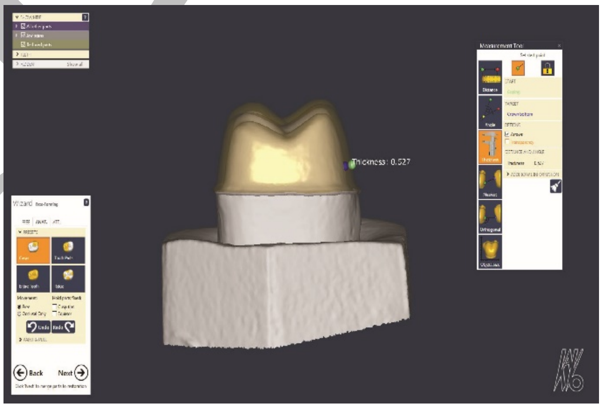


Fig. 2: The stereolithography (STL) file of coping design.

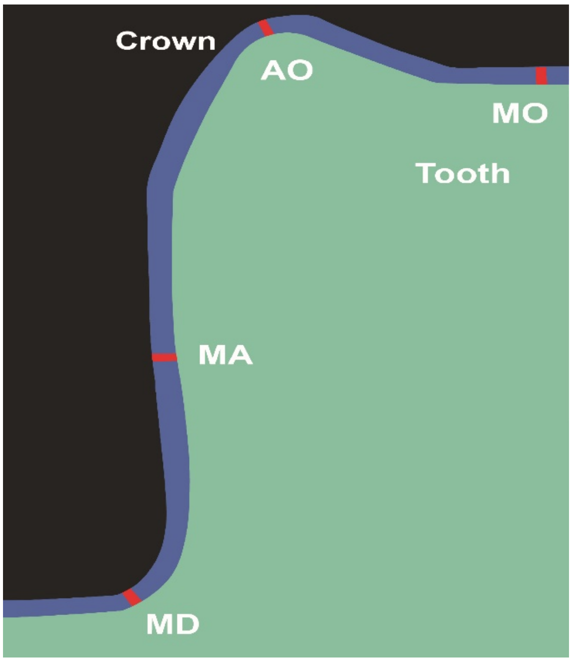


Fig. 3: Example of a cross-section of a replica. Location of measurements at Marginal Discrepancy (MD), Mid-Axial gap (MA), Axio-occlusal gap (AO), and Mid-occlusal gap (MO).

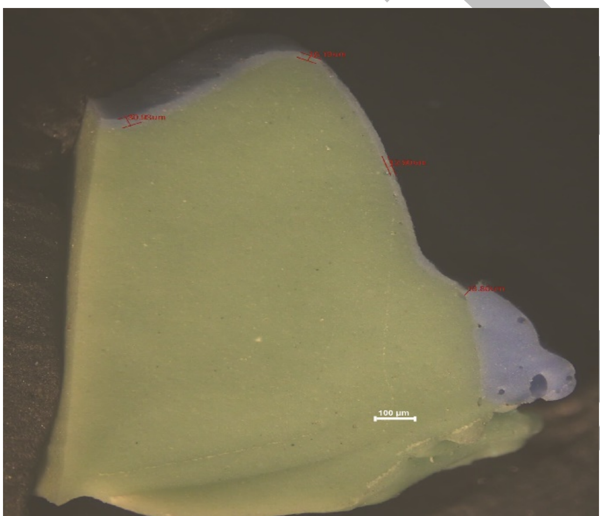


Fig. 4: Silicone replica section for measurements made of metal coping adaptation using a digital microscope (SZ1145TR Olympus x18). (Blue, light-body silicone impression material; Green, medium-body silicone impression material).

RESULTS

The mean ± standard deviation (SD) of the marginal gap in the metal coping made by milling, SLS, and casting techniques were 33.39 ± 8.11 µm, 30.57 ± 3.73 µm, and 27.83 ± 4.48 µm correspondingly (Table 1). Statistical analysis revealed no significant differences between all test groups.

The mean measurement points inside each group exhibited the best internal fit in the casted group (26.80 µm), followed by the SLS (30.15 µm) and milled group (33.60µm). Along with the various internal gap types, the mid-axial point displayed the least mean value for all test groups and the occlusal gap was the largest one (Table 2).

Statistically significant differences have been seen in the internal fit between the three manufacturing techniques (*P*=0.03, 1-way ANOVA). The highest average internal gap was seen in the milled group, which was statistically significantly different from casting copings, but not significantly different from SLS copings. There was no significant difference between the copings made by SLS and casted copings (Table 2).

Table 1: Comparison of total marginal gap and per each surface in the 3 study groups.

		Group 1 SLS	**Group 2 Milling**	**Group 3 Casting**	**F of ANOVA (P value)**
		Mean ± SD			
Total marginal gap		30.57 ± 3.73	33.39 ± 8.11	27.83 ± 4.48	2.22 (0.13)
Marginal gap/surface	**Buccal**	32.15 ± 4.14	34.66 ± 8.64	28.09 ± 3.65	3.00 (0.07)
	Palatal	28.99 ± 4.27	32.13 ± 7.89	27.57 ± 5.94	1.35 (0.28)
	Mesial	30.55 ± 4.05	32.62 ± 7.39	28.31 ± 7.14	1.09 (0.35)
	Distal	30.59 ± 4.79	34.16 ± 9.49	27.35 ± 3.07	2.75 (0.08)

Table 2: Comparison of total internal gap and per wall in the 3 study groups

		Group 1 SLS	Group 2 Milling	Group 3 Casting	F of ANOVA (P value)
		Mean ± SD			
Total internal gap		30.15 ± 4.01^{a,b}	33.60 ± 6.94^{a}	26.80 ± 3.80^{b}	4.19 (0.03*)
Gap/wall	Mid-axial	15.18 ± 1.86^{a}	11.12 ± 1.56^{b}	11.79 ± 2.97^{b}	7.73 (0.003*)
	Mid-occlusal	40.95 ± 5.75^{a,b}	49.01 ± 9.77^{a}	38.97 ± 6.35^{b}	4.60 (0.02*)
	Axio-occlusal	34.32 ± 7.30^{a,b}	40.67 ± 10.50^{a}	29.63 ± 3.38^{b}	5.12 (0.01*)

*statistically significant at p <0.05

^{a,b}Different letters denote statistically significant difference between groups using Bonferroni adjustment for multiple pairwise comparisons.

DISCUSSION

Exact marginal and internal fit are essential to fixed restorations success and longevity (14). The research aim was comparing the internal and marginal fit of metal copings produced by three different techniques; selective laser sintering, milling, and traditional lost wax method as a control using the silicone replica technique.

From the given results, the null hypothesis was accepted concerning the marginal fit as no significant difference was seen between all test groups, but regarding the internal fit, the null hypothesis was rejected since the milled copings had a statistically significant greater internal gap than casted ones.

This study was performed in vitro which offered controlled and standardized conditions in the testing process, that could never be accomplished in vivo. All the samples were manufactured by the same scanner, designed with the same CAD software, and milled with a single milling machine from the same STL file.

For the conventional casting group, castable resin patterns were milled using the same STL file used for the other two groups, instead of the traditional wax patterns constructed manually to standardize the coping design in all the test specimens and to ensure equal cement space in all the test copings. The copings' marginal and internal fit accuracy could therefore be compared, concentrating only on the various methods of metal fabrication.

The silicone replica technique used here has the advantage of being a simple, non-destructive, cost-effective, and reliable technique (6, 10). It also enabled the estimation of coping marginal and internal adaptation (5).

The Marginal discrepancy (MD) may be additional vital than the Absolute marginal discrepancy (AMD) when evaluating the marginal fit (3). AMD is representative of the proper crown margins' extension as opposed to the abutment margins, but MD does refer to an intra-orally exposed cement surface that would dissolve as a result of a microleakage causing secondary caries and pulp consequences (14, 20). The total of measurement points per crown utilized in preceding research differed significantly. Parameters in other studies ranged from four to twelve (21). In this study, we evaluate 32 measurements for each coping 8 of them for the marginal gap.

In this research, the mean marginal gap of the three groups ranged from 27-34 micron, that were inside the clinically acceptable vary (16-18). The casted copings group displayed lesser marginal discrepancy than the milled and SLS groups, which is in agreement with Hong et al (22) and Kim et al (6), but no significant difference was found between all test groups.

This can be illustrated by the milled group's hard material, the Co-Cr alloy block, that is much complicated to cut accurately because of its hardness. The precision of the milling procedure could be impaired by further oscillation and milling axis friction during the cutting process. In addition, the castable resin pattern of this study replacing the manual wax pattern, may have contributed to the relatively lesser marginal discrepancy of the casted copings than those recorded in other studies by Xu et al (8) and Zeng et al (16).

Although the CAD-CAM technique requires fewer manufacturing steps especially in comparison to the lost wax method and simplifies manufacturing with reduction of the waste materials and faster performance, the marginal and internal fit of the restorations made by these methods are subject to several variables effect, together with the scanner accuracy accustomed to digitize a working model, the computer software used to create the 3D design, and also the machine quality inured to generate this design (23).

In this study, the SLS copings exhibited significantly the highest average axial gaps in comparison to the other two manufacturing techniques. This could be explained by the rapid solidification of Co-Cr powder taking place in small sections. This might reduce the alloy's chances of shrinking (15).

The milled copings showed the smallest axial gap which might explain the greater marginal and occlusal gaps. There is an inverse relationship linking the marginal and internal fit of CAD-CAM systems used, as stated by Vojdani et al (24). A smaller axial gap may lead to incomplete restoration seating and thus lead to a greater occlusal and marginal gap due to the restoration binding with the die.

The milling group presented the largest axio-occlusal gap through all test groups. This might be due to drill compensation where the areas smaller than the bur diameter are over-milled. This explanation is in agreement with Ortorp et al (7). While in SLS, there is no drill compensation in CAD design. Casting shrinkage most probably is the cause of smaller gaps in casted copings, besides the difference in hardness between the resin and metal alloy milling.

Our results are in agreement with the research by Kim et al (9) concerning the marginal integrity which showed that the casted group exhibited the lowest marginal discrepancy values. There is also agreement between the findings of this study and the research by Ucar et al (25) which stated that the internal gap of fixed dental prostheses manufactured by the SLS was greater than those made by the lost wax method.

There is a disagreement between this research results with those of studies conducted by Harish et al (15), Zeng et al (16), and Gunsoy et al (11) who found that the SLS copings displayed the best marginal and internal fit relative to other fabrication techniques. Also, there is another disagreement between us, and a study done by Nesse et al (10) who stated that the milling technique had the best fit, whereas selective laser melting restorations had the worst results. This disagreement may be due to the various shapes of the dies, dissimilar types of abutment teeth, and the different methodologies adopted by the researchers.

This study has a few limitations. Just one type of alloy (Co-Cr) was used, and only a single metal coping was analyzed. Further research is therefore required, comparing the fit before and after porcelain veneering using various commercial brands of alloys and laser systems not only for single metal copings, but also for long-span fixed partial prostheses.

CONCLUSIONS

The following conclusions can be made under the boundaries of this study:

All techniques tested in the current study produced copings of clinically acceptable fit accuracy.
The marginal gap was minimal in the cast group followed by SLS then milled copings.
The internal fit of the casted copings was significantly better than the milled ones (P=0.03).
CONFLICTS OF INTEREST: none
FUNDING: The authors received no specific funding for this work.

REFERENCES

1. Kaleli N, Saraç D. Influence of porcelain firing and cementation on the marginal adaptation of metal-ceramic restorations prepared by different methods. J Prosthet Dent. 2017 May;117:656-61.
2. Kocaağaoğlu H, Kılınç Hİ, Albayrak H, Kara M. In vitro evaluation of marginal, axial, and occlusal discrepancies in metal ceramic restorations produced with new technologies. J Prosthet Dent. 2016 Sep;116:368–74.
3. Kim KB, Kim WC, Kim HY, Kim JH. An evaluation of marginal fit of three-unit fixed dental prostheses fabricated by direct metal laser sintering system. Dent Mater. 2013 Jul;29:e91–6.
4. 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;112:909–13.
5. Kim KB, Kim JH, Kim WC, Kim JH. Three-dimensional evaluation of gaps associated with fixed dental prostheses fabricated with new technologies. J Prosthet Dent. 2014 Dec;112:1432–6.
6. Kim DY, Kim JH, Kim HY, Kim WC. Comparison and evaluation of marginal and internal gaps in cobalt-chromium alloy copings fabricated using subtractive and additive manufacturing. J Prosthodont Res. 2018 Jan;62:56–64.
7. Örtorp A, Jönsson D, Mouhsen A, Vult von Steyern P. The fit of cobalt-chromium three-unit fixed dental prostheses fabricated with four different techniques: a comparative in vitro study. Dent Mater. 2011 Apr;27:356–63.
8. Xu D, Xiang N, Wei B. The marginal fit of selective laser melting-fabricated metal crowns: an in vitro study. J Prosthet Dent. 2014 Dec;112:1437–40.
9. Kim MJ, Choi YJ, Kim SK, Heo SJ, Koak JY. Kim MJ, Choi YJ, Kim SK, Heo SJ, Koak JY. Marginal Accuracy and Internal Fit of 3-D Printing Laser-Sintered Co-Cr Alloy Copings. Materials (Basel). 2017;10:93.
10. Nesse H, Ulstein DM, Vaage MM, Øilo M. Internal and marginal fit of cobalt-chromium fixed dental prostheses fabricated with 3 different techniques. J Prosthet Dent. 2015 Nov;114:686–92.
11. Gunsoy S, Ulusoy M. Evaluation of marginal/internal fit of chrome-cobalt crowns: direct laser metal sintering versus computer-aided design and computer-aided manufacturing. Niger J Clin Pract. 2016 Sep-Oct;19:636–44.
12. Venkatesh KV, Nandini VV. Direct metal laser sintering: a digitised metal casting technology. J Indian Prosthodont Soc. 2013 Dec;13:389–92.
13. Sundar MK, Chikmagalur SB, Pasha F. Marginal fit and microleakage of cast and metal laser sintered copings—an in vitro study. J Prosthodont Res. 2014 Oct;58:252–8.
14. Felton DA, Kanoy BE, Bayne SC, Wirthman GP. Effect of in vivo crown margin discrepancies on periodontal health. J Prosthet Dent. 1991 Mar;65:357–64.
15. Harish V, Mohamed Ali SA, Jagadesan N, Ifthikar M, Senthil S, Basak D, et al. Evaluation of internal and marginal fit of two metal ceramic system - in vitro study. J Clin Diagn Res 2014;8:Zc53-6.
16. Zeng L, Zhang Y, Liu Z, Wei B. Effects of repeated firing on the marginal accuracy of Co-Cr copings fabricated by selective laser melting. *J Prosthet Dent*. 2015; 113:135-139.
17. Sulaiman F, Chai J, Jameson LM, Wozniak WT. A comparison of the marginal fit of In-Ceram, IPS Empress, and Procera crowns. Int J Prosthodont. 1997 Sep-Oct;10:478–84.
18. McLean JW, von Fraunhofer JA. The estimation of cement film thickness by an in vivo technique. Br Dent J. 1971 Aug;131:107–11.
19. Moldovan O, Rudolph H, Quaas S, Bornemann G, Luthardt R. Internal and external fit of CAM-made zirconia bridge frameworks-a pilotstudy. Dtsch Zahnarztl Z. 2006;61:38–42.
20. Holmes JR, Bayne SC, Holland GA, Sulik WD. Considerations in measurement of marginal fit. J Prosthet Dent. 1989 Oct;62:405–8.
21. Sorensen JA. A standardized method for determination of crown margin fidelity. J Prosthet Dent. 1990 Jul;64:18–24.
22. 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;122:475–81.
23. Al Jabbari YS, Koutsoukis T, Barmpagadaki X, Zinelis S. Metallurgical and interfacial characterization of PFM Co-Cr dental alloys fabricated via casting, milling or selective laser melting. Dent Mater. 2014 Apr;30:e79–88.
24. Vojdani M, Torabi K, Farjood E, Khaledi A. Comparison the Marginal and Internal Fit of Metal Copings Cast from Wax Patterns Fabricated by CAD/CAM and Conventional Wax up Techniques. J Dent (Shiraz). 2013 Sep;14:118–29.
25. Ucar Y, Akova T, Akyil MS, Brantley WA. Internal fit evaluation of crowns prepared using a new dental crown fabrication technique: laser-sintered Co-Cr crowns. J Prosthet Dent. 2009 Oct;102:253–9.