Dental Research Journal

Original Article

# Fit of cobalt-chromium copings fabricated by the selective laser melting technology and casting method: A comparative evaluation using a profilometer

**Koosha Gholamrezaei[1], Fariborz Vafaee[2], Behzad Fathi Afkari[2], Farnaz Firouz[2], Mozhgan Seif[3]**

[1]School of Dentistry, Shahid Beheshti University of Medical Sciences, Tehran, [2]Department of Prosthodontics, School of Dental Medicine, Hamadan University of Medical Sciences, Hamadan, [3]Department of Epidemiology, School of Health, Shiraz University of Medical Sciences, Shiraz, Iran

## ABSTRACT

**Background:** This study aimed to assess the marginal adaptation and internal fit of cobalt-chromium copings fabricated by the selective laser melting (SLM) and conventional techniques using a profilometer.

**Materials and Methods:** In this in vitro study sample size was calculated to be a total of 10 in two groups ($n = 5$). A brass model was used that had a circular cross-section with a round shoulder margin with 0.5 mm thickness and axial walls with 10 mm length and 6° taper. The copings fabricated with both techniques (SLM and casting method) were placed on the model, and vertical marginal gap was measured using a profilometer. The internal fit of copings was assessed by weighing the light-body addition silicone applied inside them, which simulated the cement. Data were analyzed through parametric (Independent *t*-test) and nonparametric (Mann–Whitney U-test, Bootstrap, Spearman, and Pearson Correlation) analysis. All analyses were performed at a significant level ($\alpha = 0.05$) using SPSS.

**Results:** The mean marginal gap in the casting group (132.93 ± ) was significantly higher than that in the SLM group (67.14 ± 15.67 μm) ($P < 0.05$). The mean weight of light-body silicone was 9.60 ± in the SLM and 8.70 ± 1.21 mg in the casting group. No significant difference was noted between the two groups regarding the internal fit ($P > 0.05$).

**Conclusion:** The copings fabricated by the SLM technique showed a smaller vertical marginal gap compared to the casting group. However, the two groups were not significantly different in terms of internal fit.

**Key Words:** Dental marginal adaptation, dental prostheses, laser, prosthesis fitting

**Received:** February 2019
**Accepted:** June 2019

**Address for correspondence:**
Dr. Farnaz Firouz,
Department of Prosthodontics, School of Dental Medicine, Hamadan University of Medical Sciences, Hamadan, Iran.
E-mail: drfirouzfarnaz@gmail.com

## INTRODUCTION

Optimal marginal adaptation and internal fit are among the main criteria for long-term success of all types of crowns, including metal-ceramic restorations.[1-3] Poor marginal adaptation can lead to plaque accumulation, microleakage, cement washout and degradation and subsequent leakage of bacteria and saliva through the gap, which may eventually result in pulpal inflammation, recurrent caries, and periodontal disease.[4]

Access this article online

Website: www.drj.ir
www.drjjournal.net
www.ncbi.nlm.nih.gov/pmc/journals/1480



**How to cite this article:** Gholamrezaei K, Vafaee F, Afkari BF, Firouz F, Seif M. Fit of cobalt-chromium copings fabricated by the selective laser melting technology and casting method: A comparative evaluation using a profilometer. Dent Res J 2020;17:200-7.

At present, cobalt-chromium alloys are more commonly used than nickel–chromium alloys for the fabrication of metal frameworks of fixed partial dentures.[5] Electrochemical studies have shown that cobalt-chromium alloys are more resistant to corrosion than nickel–chromium alloys. Moreover, nickel-based alloys are more allergen.[6]

Marginal adaptation of metal-ceramic crowns highly depends on their fabrication process. The conventional method for the fabrication of metal frameworks includes the lost-wax technique and the use of metal alloys for casting.[7] Wax has many inherent limitations such as fineness, heat sensitivity, and high elastic memory and high coefficient of thermal expansion.[8]

The newly introduced computer-aided design/computer-aided manufacturing (CAD/CAM) laser melting is an additional fabrication process for metal copings of metal-ceramic crowns.[9-13] This technique does not have the limitations of the conventional waxing and lost-wax technique. Selective laser melting (SLM) uses high-temperature laser beams for selective heating of the metal framework, which is in the form of powder and uses the CAD data obtained from designing the framework for this purpose.[14] SLM has many advantages including the fabrication of restorations with a more homogeneous quality, standardization of the process of restoration shaping, less production costs, requiring fewer human resources and shorter time and the potential to yield higher accuracy due to the elimination of multiple procedural steps such as wax-up, flasking, and casting. However, the SLM scanners have disadvantages as well. For instance, the scanner systems have limited resolution, which can lead to slightly rounder margins.[15-18]

Only a few studies have compared marginal adaptation/internal fit of restorations fabricated by the SLM technique with metal copings or crowns fabricated by the conventional technique.[11,12,15,19] However, comparison of the results of these studies is difficult due to variations in sample size, measurement methods, cement space, and laser systems.

Among the available tools for the measurement of gap and marginal adaptation, profilometry is a noninvasive method, which visualizes the die and sample in the same focal plane on a monitor and thus, enables more accurate focus.[7,20]

Considering the advantages and disadvantages of both the conventional waxing and SLM techniques, the significance of optimal marginal adaptation and internal fit and since a profilometer has not been previously used for this purpose, this study aimed to assess the marginal adaptation and internal fit of cobalt-chromium copings fabricated by the SLM and conventional techniques using a profilometer.

The null hypothesis stated that the samples fabricated using the two methods would have no difference with each other in terms of marginal and internal fit.

## MATERIALS AND METHODS

In this *in vitro* study, the sample size was calculated to be five samples for each technique (a total of 10).

A brass model [Figure 1] along with its counterpart milled by a milling machine (CNC 350; Arix Co., Taiwan) was used as a model of prepared tooth for this study. This model had a circular cross-section with 8 mm diameter at the tip and 10 mm diameter at the base along with a round shoulder margin at the periphery with 0.5 mm thickness and axial walls with 10 mm length and 6° taper. The counterpart surrounded all the walls with 0.5 mm distance.[14]

A stone master die was produced by taking an impression of the brass model using polyvinyl siloxane impression material (Panasil, Kettenbach GmbH, Germany) and pouring it with Type IV dental stone (Fujirock EP; GC Europe, Belgium) [Figure 2].[21]

To fabricate the copings, first, the die was scanned by a laser scanner (D810; 3Shape, Denmark). The collected data were transferred to CAD software (3Shape; Denmark) [Figure 3].

After identifying the die margin by the operator, a cylindrical coping was designed with 0.5 mm thickness of the walls and the occlusal surface, along

**Figure 1:** Brass die along with its counterpart.

with 30 μm of cement space starting at 1 mm above the margin [Figure 4]. Data in STL format were

**Figure 2:** Die stone.

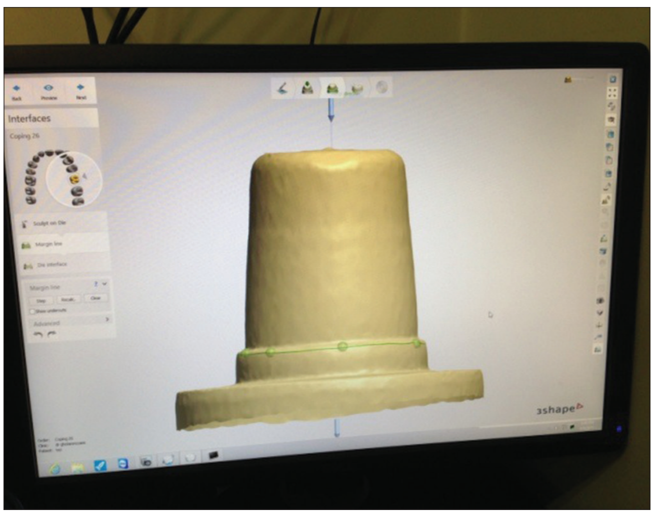


**Figure 3:** Die scanned by the computer-aided manufacturing software.

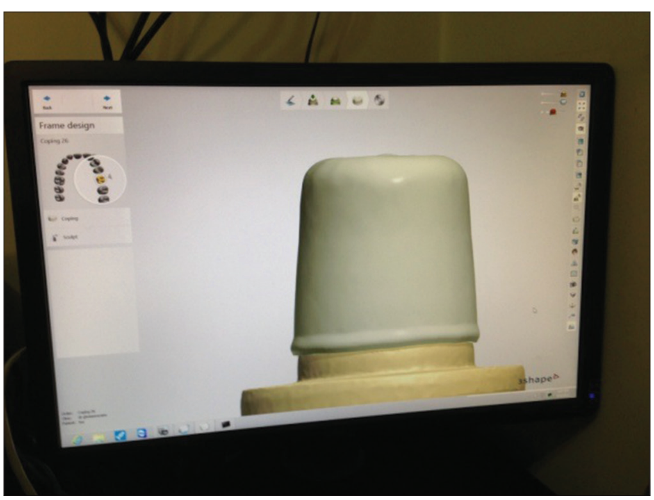


**Figure 4:** Designing the coping by the computer-aided design software.

E-mailed to BEGO Company in Germany. The SLM device (EOSINT M270, ESO GmbH, Germany) was used for the fabrication of metal copings in this study.

This device uses a condensed direct high-energy fiber laser beam for local melting of a thin layer of metal powder with 20 μm thickness for the incremental fabrication of metal coping. The laser wavelength ranges from 1060 to 1100 nm, and its maximum power is 200 W. The laser speed is 7000 mm/s, and the diameter of laser beam is around 0.1 mm.

Five copings were fabricated of cobalt-chromium alloy (Wirobond C+, BEGO Medical GmbH, Germany) by the SLM technique. The composition of alloy was as follows: Co 63.9%, Cr 24.7%, W 5.4%, Mo 5%, and Si ≤1%

The same stone die was used for the fabrication of wax copings by the conventional method. For this purpose, first, two layers of die spacer were applied on the die 1 mm above the margin. According to the catalog of this product, each layer of the die spacer has 12–15 μ thickness. Thus, by applying two coats, 30 μ thickness is obtained. The samples were standardized as such.[22,23] After drying of the die spacer, a thin layer of the separator was applied on the die surface (Picosep; Renfert GmbH, Germany). Next, the inlay wax was melted and poured into the counterpart, which had been previously lubricated and positioned upside down on a table. The master die was placed over it until the bottom part of the counterpart reached the horizontal plate of the die. After cooling of the wax, the die was separated from the counterpart.

For finishing of the margins, an electrical waxing tool (Kerr Corporation Lab, USA) was used to completely heat and melt the marginal 1–2 mm of the wax. Thus, the wax pattern with 0.5 mm uniform thickness in all walls was obtained, and we ensured marginal adaptation with the finish line on the die.

The wax patterns were sprued and invested using phosphate-bonded investment material (Z4-CandB investment; Neirynck and Vogt, Belgium) with a liquid to powder ratio of 24 mL/100 g. After heating the investment material to 950° for wax burnout, the copings were cast with cobalt-chromium alloy (D. SIGN 30, Ivocolar vivadent, Liechtenstein) using a centrifuge (Nautilus cc plus; BEGO Medical GmbH, Germany). The castings were separated from the investment, and the residual investment material was removed using a sandblaster (Basic mo-bil, Renfert, Germany) with 3-bar pressure and 50-μm aluminum oxide particles. They were then routinely finished and polished in the laboratory.

Next, the adaptation of copings was evaluated visually and use of a dental explorer. For this purpose, first, metal nodules visible on the internal surface of the copings were removed by a round tungsten carbide bur and a handpiece. To find unnoticed nodules and irregularities, the internal surface of the copings on the master metal dies was evaluated using vinyl siloxane pressure indicating paste (Fit Checker; GC, USA). The adjustment was repeated until an equal thickness of fit checker was obtained, and adaptation of the crown with the die was clinically optimal both visually and when examined using a dental explorer.

In order to assess the internal fit of samples, light-body addition silicone impression material (Panasil; Kettenbach GmbH, Germany) was used.[3] For this purpose, first, microfilm (Kerr, USA) was applied on the metal model. Then, equal amounts of silicone base and catalyst were mixed and applied to the crown. The crown was compressed over the die for 2 min with finger pressure to simulate cementation of crown in the clinical setting. Next, excess cement was removed. After the completion of silicone polymerization, the coping was removed from the master die, and the silicone material was separated from the coping carefully and weighed using a digital scale (Analytic; Shimadzu, Japan) with 0.1 mg accuracy as an indication of the internal fit.

Next, the copings were placed over the metal die, and their marginal adaptation was evaluated by a profilometer (Talyscan 150; Taylor Hobson, England) with 0.1 μm accuracy. Profilometer is an optical measurement tool that displays a magnified image of a sample on a monitor. It can be adjusted in vertical (x), horizontal (y), and focusing (z) planes.[24] In the present study, this tool was used for the measurement of distances between the reference points at 12 locations in the vertical plane. These points were marked on the circular inferior surface of the metal model by drawing six diameters with 30° angles [Figure 5]. For measurements in the vertical plane, the tool was focused on the outermost point of the margin of coping and reference mark on the die. After fixing the outermost point of the margin of coping at the center of screen, the stylus was moved along the horizontal axis until the reference point was seen at the center of screen. In fact, vertical measurements were made along the longitudinal axis of the die between the coping margin and reference points on the die.

Talyscan 150 is a device with contact and noncontact scanners. The contact gauge was used in this study. This device works with Talymap three-dimensional (3D) analysis software. The discrepancy between the crown margin and finishing line of the samples was measured at the above-mentioned 12 points on the original model. The marginal gap was measured along these points from the copings to the dies. The mean of the 12 values was calculated and reported as the marginal gap of each coping. All measurements were made with the profilometer stylus [Figure 6], by the same operator.

Independent *t*-test was used to compare the groups and its precondition, which is the equality of variance of the groups, was evaluated by the Levene's test. Since the sample size is relatively low in the application of the parametric test, the nonparametric Mann–Whitney U-test and Bootstrap confidence

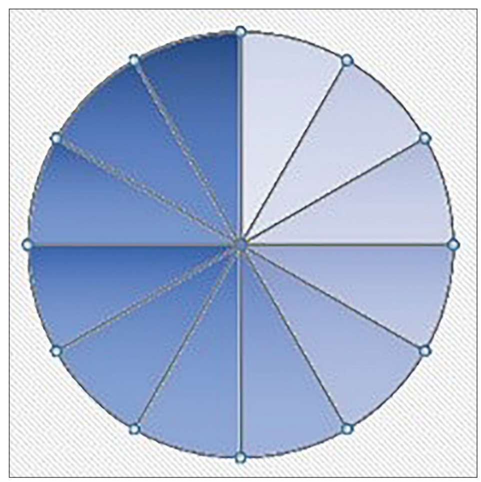

**Figure 5:** Reference points.

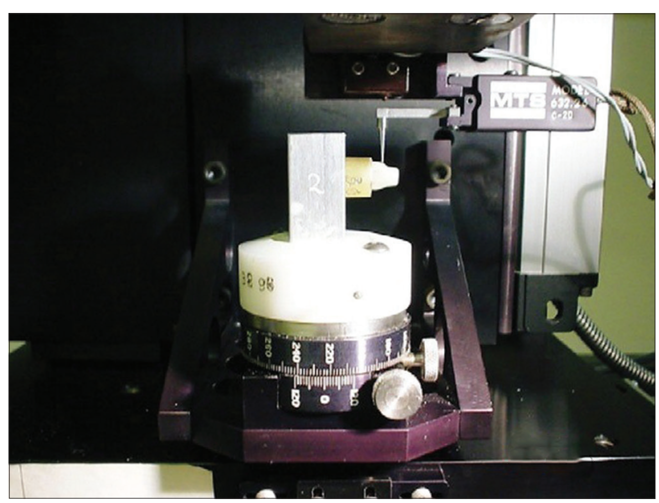

**Figure 6:** Measurement of marginal gap.

**Table 1: Comparison of the mean marginal and internal gap between selective laser melting and casting groups using *t*-test**

| Type of gap | Group | Mean (µm)±SD | *P*, *t*-test | *P* Mann-Whitney test | 95% bootstrap CI | |
|---|---|---|---|---|---|---|
| | | | | | Lower bound | Upper bound |
| Marginal gap | SLM | 67.14±15.67 | 0.02 | 0.01 | 54.75 | 80.87 |
| | Casting | 132.93±27.91 | | | 111.39 | 158.35 |
| Internal gap | SLM | 9.60±1.29 | 0.29 | 0.22 | 8.57 | 10.60 |
| | Casting | 8.70±1.21 | | | 7.80 | 9.77 |

SD: Standard deviation; SLM: Selective laser melting; CI: Confidence interval

intervals are used to compare the mean of the groups. It should be noted that in the correlation study, addition Spearman Correlation, Pearson Correlation is also used, which is a nonparametric method and has less sensitivity to sample size. All analyses were performed at a significant level ($\alpha = 0.05$) using SPSS version 16 (SPSS Inc., IL, USA).

## RESULTS

As shown in Table 1, a significant difference existed in the marginal gap between the casting and SLM groups in that the mean marginal gap was lower in SLM group ($P < 0.05$). According to Bootstrap test, the mean marginal gap in the SLM group was not within the confidence interval of the casting group. Furthermore, the mean marginal gap of the casting group was not within the confidence interval of the SLM group. Thus, nonparametric test (Mann–Whitney test) also confirmed that the difference in this respect was significant between the two groups ($P < 0.05$).

As shown in Table 1, the difference between the casting and SLM groups in the internal gap was not significant. ($P > 0.05$) According to Bootstrap test, the mean internal gap (= weight of the internal silicone material) of the SLM group was within the confidence interval of the casting group. The mean internal gap of the casting group was within the confidence interval of the SLM group as well. Thus, nonparametric test (Mann–Whitney test) also failed to show a significant difference between the two groups ($P > 0.05$).

As shown in Table 2, according to the Pearson and Spearman correlation tests, there was no correlation between the internal gap and marginal gap in the SLM and casting groups.

## DISCUSSION

The current results rejected the null hypothesis of this study since there was a significant difference

**Table 2: Pearson's and spearman correlation test in both groups**

| Type of group | Type of gap | Pearson correlation | | Spearman correlation | |
|---|---|---|---|---|---|
| | | Coefficient | *P* | Coefficient | *P* |
| SLM | Marginal gap | 0.27 | 0.65 | 0.30 | 0.62 |
| | Internal gap | | | | |
| Casting | Marginal gap | −0.80 | 0.10 | −0.90 | 0.03 |
| | Internal gap | | | | |

SLM: Selective laser melting

in marginal adaptation between the two methods of fabrication of copings. Marginal adaptation in the SLM group was superior to that of the conventional casting group, but the internal fit of the two groups was not significantly different.

In the present study, a brass die was used as abutment. Many researchers have used metal, or acrylic resin dies for the measurement of the marginal gap.[3,14,25,26] The advantages of metal die include standardized preparation and no wear during the measurement and fabrication process. Some studies have shown that due to differences in the seating of crown in different areas, the magnitude of marginal gap may vary at different points on a die.[27-29] However, Holmes *et al*.[1] hypothesized that the crown seating in different areas was not significantly different, and our findings supported their statement.

The sample size varied from 5 to 10 samples in each group in previous studies.[14,19,30,31] Thus, five samples were fabricated by each method. The low volume of sample was due to financial problems in the project, but it has no effect on the results of the project because in the statistical analyses, in addition to parametric analyzes, nonparametric analyzes have also been used and the results of all analyzes are in concordant with each other, and the results have been confirmed by each other.

Measurements were made at 12 points on each sample in our study. Therefore, the mean discrepancy value could be generalized to the entire margin. The measurement techniques often involve sectioning of the crown and die and measuring the marginal gap under a light or scanning electron microscope. These techniques have the potential to cause distortion artifact and provide limited number and sites of measurements. Moreover, these techniques are considered invasive.[32] However, the use of a contact profilometer is noninvasive and allows multiple measurements between the finish line and final coping. The profilometer visualizes the die and the sample in the same plane and therefore, allows accurate focusing. In the present study, the marginal gap was quantified using profilometry, and the results showed that the marginal gap in the SLM group was significantly smaller than the casting group.

In this study, the terminology suggested by Holmes *et al*.,[1] for the assessment of marginal adaptation was used. Accordingly, the absolute marginal discrepancy, which is defined as the vertical distance between the coping margin and finish line was measured at 12 points for each coping, and the mean of 12 values was considered as the mean marginal gap of the entire crown.

The majority of researchers follow the principles of McLean and von Fraunhofer[33] to describe the greatest width of the clinical marginal gap. The two authors in a 5-year study on 1000 restorations concluded that marginal gap by 120 µm yields the best clinical results.[33] Accordingly, only the marginal gap in the SLM group was <120 µm and within the clinically acceptable range in our study. However, according to Moldovan *et al*.,[34] marginal gap by up to 100 µm is considered good and marginal discrepancy between 200–300 µm is considered acceptable. Accordingly, the marginal gap in our study (132.93 µm in the conventional casting group and 68.94 µm in the SLM group) was clinically acceptable and in accordance with the ranges reported by McLean and von Fraunhofer, White *et al*., Dedmon and Hung *et al*.[30,33,35,36]

In the present study, slightly higher marginal gap in the casting group can be attributed to the shrinkage and stress release by the inlay wax and inherent inaccuracy of the investment material. The composition of the cobalt-chromium alloy powder used in the SLM technique differs from the casting material. The molybdenum content of the former is less than that in the alloy used for casting. This enhances the laser melting of the alloy because molybdenum has a higher melting point than the cobalt and chromium.

Moreover, the SLM technique completely eliminates the casting processes and the related human errors and yields superior results. Furthermore, since cast restorations are fabricated on a stone die obtained from polyvinyl siloxane impressions, marginal gap may be affected by the shrinkage of impression material or dental stone, deformation of wax pattern and differences in the thickness of spacer. However, these steps are eliminated in the SLM technique, which would allow the crown to be directly transferred to the patient's mouth without requiring such steps.

Several techniques have been employed to assess the internal fit of restorations such as scanning electron microscopy, stereomicroscope, resin replica technique, and weighing the light-body silicon. All these techniques, except for the weighing method, enable a 2D assessment only in a plane obtained by longitudinal sectioning of the coping.[1,3,4,37] However, the amount of light-body silicone entrapped between the coping and die indicates the entire space that exists between the coping and die and therefore, enables a 3D assessment of the fit of coping.

In the current study, the light-body silicone was weighed to assess the internal fit of restorations. According to the results, the SLM group showed a higher mean weight than the casting group but not significantly. In a study by Ucar *et al*., the internal fit of metal crowns fabricated by the casting and SLM techniques was evaluated and compared by two methods of weighting the light-body silicone and sectioning. The results showed a difference between the two methods in that the weight of light-body in the casting method was significantly less than that in the SLM technique. However, when the internal fit of crowns was evaluated using the sectioning method, the casting group had no significant difference with the SLM group although the mean value was lower in the casting method. Variations in values reported in our study and previous investigations may be attributed to the method of measurement, type of die, accuracy of scanners, and measurement of gap in noncemented copings.

Zeng *et al*.[18] stated that the SLM alloy shows a homogeneous microstructure while the cast alloy shows a typical dendritic microstructure. Highly different microstructure of cobalt-chromium alloys fabricated by the SLM and casting techniques results in a totally different corrosion behavior. Due to the fine scale microstructure, the SLM alloy shows better anti-corrosion properties, which helps in maintaining the marginal integrity of SLM metal copings in the long-term.[18] Thus, SLM metal copings are preferred for clinical application. In addition, in the present study, the mean internal gap in the SLM group was higher than that in the casting group, which may possibly be due to the fact that during scanning of the original die and fabrication of 3D model, the margin was manually adjusted while the external die surface was scanned by the offsetting algorithm of the scanning software.

The CAD/CAM process benefits from automated scanning and a strong CAD software for the fabrication of copings using SLM. This has several advantages such as complete control over the coping design and frameworks, marginal integrity, maintaining the cement space, coping thickness, pontic design, and elimination of casting processes.

The difference in elastic modulus of brass die and dentin was a limitation of this study. *In vitro* design was another limitation of this study since oral conditions cannot be perfectly simulated *in vitro*.

## CONCLUSION

The copings fabricated by the SLM technique showed a smaller vertical marginal gap compared to the casting group. However, the two groups were not significantly different in terms of internal fit.

### Acknowledgment

This article was written based on a dissertation for a specialty degree in prosthodontics. The authors would like to extend their gratitude to the Deputy of Research at Hamadan University of Medical Sciences, and the Dental Research Center for the financial support provided.

### Financial support and sponsorship

This study was supported by Hamadan University of Medical Sciences, Hamadan, Iran.

### Conflicts of interest

The authors of this manuscript declare that they have no conflicts of interest, real or perceived, financial or non-financial in this article.

## REFERENCES

1. Holmes JR, Bayne SC, Holland GA, Sulik WD. Considerations in measurement of marginal fit. J Prosthet Dent 1989;62:405-8.
2. Schwartz IS. A review of methods and techniques to improve the fit of cast restorations. J Prosthet Dent 1986;56:279-83.
3. 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;102:253-9.
4. Bindl A, Mörmann WH. Marginal and internal fit of all-ceramic CAD/CAM crown-copings on chamfer preparations. J Oral Rehabil 2005;32:441-7.
5. Wataha JC, Messer RL. Casting alloys. Dent Clin North Am 2004;48:vii-viii, 499-512.
6. Wiltshire WA, Ferreira MR, Ligthelm AJ. Allergies to dental materials. Quintessence Int 1996;27:513-20.
7. Kenneth J. Anusavice CS, H. Ralph rawls. In: Phillips' Science of Dental Materials. China. Elsevier; 2003.
8. Iglesias A, Powers JM, Pierpont HP. Accuracy of wax, autopolymerized, and light-polymerized resin pattern materials. J Prosthodont 1996;5:201-5.
9. Akçin ET, Güncü MB, Aktaş G, Aslan Y. Effect of manufacturing techniques on the marginal and internal fit of cobalt-chromium implant-supported multiunit frameworks. J Prosthet Dent 2018;120:715-20.
10. Kang SY, Lee HN, Kim JH, Kim WC. Evaluation of marginal discrepancy of pressable ceramic veneer fabricated using CAD/CAM system: Additive and subtractive manufacturing. J Adv Prosthodont 2018;10:347-53.
11. Liu W, Qing H, Pei X, Wang J. Internal adaptation of cobalt-chromium posts fabricated by selective laser melting technology. J Prosthet Dent 2019;121:455-60.
12. Revilla-León M, Ceballos L, Martínez-Klemm I, Özcan M. Discrepancy of complete-arch titanium frameworks manufactured using selective laser melting and electron beam melting additive manufacturing technologies. J Prosthet Dent 2018;120:942-7.
13. Livescu V, Knapp CM, Gray GT, Martinez RM, Morrow BM, Ndefru BG. Additively manufactured tantalum microstructures. Materialia 2018;1:15-24.
14. Bhaskaran E, Azhagarasan NS, Miglani S, Ilango T, Krishna GP, Gajapathi B. Comparative evaluation of marginal and internal gap of Co-Cr copings fabricated from conventional wax pattern, 3D printed resin pattern and DMLS tech: An *in vitro* study. J Indian Prosthodont Soc 2013;13:189-95.
15. 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;113:623-7.
16. Li JM, Wang WQ, Ma JY. Comparison of the clinical effects of selective laser melting deposition basal crowns and cobalt chromium alloy base crowns. Shanghai Kou Qiang Yi Xue 2014;23:350-3.
17. Wu L, Zhu H, Gai X, Wang Y. Evaluation of the mechanical properties and porcelain bond strength of cobalt-chromium dental alloy fabricated by selective laser melting. J Prosthet Dent 2014;111:51-5.
18. Zeng L, Xiang N, Wei B. A comparison of corrosion resistance of cobalt-chromium-molybdenum metal ceramic alloy fabricated with selective laser melting and traditional processing. J Prosthet Dent 2014;112:1217-24.

19. Xu D, Xiang N, Wei B. The marginal fit of selective laser melting-fabricated metal crowns: An *in vitro* study. J Prosthet Dent 2014;112:1437-40.
20. Mitchell CA, Pintado MR, Douglas WH. Nondestructive, *in vitro* quantification of crown margins. J Prosthet Dent 2001;85:575-84.
21. 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;14:118-29.
22. Komine F, Iwai T, Kobayashi K, Matsumura H. Marginal and internal adaptation of zirconium dioxide ceramic copings and crowns with different finish line designs. Dent Mater J 2007;26:659-64.
23. Martins LM, Lorenzoni FC, Melo AO, Silva LM, Oliveira JL, Oliveira PC, *et al.* Internal fit of two all-ceramic systems and metal-ceramic crowns. J Appl Oral Sci 2012;20:235-40.
24. Balkaya MC, Cinar A, Pamuk S. Influence of firing cycles on the margin distortion of 3 all-ceramic crown systems. J Prosthet Dent 2005;93:346-55.
25. Bhowmik H, Parkhedkar R. A comparison of marginal fit of glass infiltrated alumina copings fabricated using two different techniques and the effect of firing cycles over them. J Adv Prosthodont 2011;3:196-203.
26. Quintas AF, Oliveira F, Bottino MA. Vertical marginal discrepancy of ceramic copings with different ceramic materials, finish lines, and luting agents: An *in vitro* evaluation. J Prosthet Dent 2004;92:250-7.
27. Gassino G, Barone Monfrin S, Scanu M, Spina G, Preti G. Marginal adaptation of fixed prosthodontics: A new *in vitro* 360-degree external examination procedure. Int J Prosthodont 2004;17:218-23.
28. Groten M, Girthofer S, Pröbster L. Marginal fit consistency of copy-milled all-ceramic crowns during fabrication by light and scanning electron microscopic analysis *in vitro*. J Oral Rehabil 1997;24:871-81.
29. Romeo E, Iorio M, Storelli S, Camandona M, Abati S. Marginal adaptation of full-coverage CAD/CAM restorations: *In vitro* study using a non-destructive method. Minerva Stomatol 2009;58:61-72.
30. Dedmon HW. The relationship between open margins and margin designs on full cast crowns made by commercial dental laboratories. J Prosthet Dent 1985;53:463-6.
31. 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;112:909-13.
32. Nawafleh NA, Mack F, Evans J, Mackay J, Hatamleh MM. Accuracy and reliability of methods to measure marginal adaptation of crowns and FDPs: A literature review. J Prosthodont 2013;22:419-28.
33. McLean JW, von Fraunhofer JA. The estimation of cement film thickness by an *in vivo* technique. Br Dent J 1971;131:107-11.
34. Moldovan OR, Rudolph H, Quaas S, Bornemann G, Luthardt R. Internal and external fit of CAM-made zirconia bridge frameworks-a pilot study. Dtsch Zahnarztl Z 2006;61:38.
35. Hung SH, Hung KS, Eick JD, Chappell RP. Marginal fit of porcelain-fused-to-metal and two types of ceramic crown. J Prosthet Dent 1990;63:26-31.
36. White SN, Yu Z, Tom JF, Sangsurasak S. *In vivo* marginal adaptation of cast crowns luted with different cements. J Prosthet Dent 1995;74:25-32.
37. Fransson B, Oilo G, Gjeitanger R. The fit of metal-ceramic crowns, a clinical study. Dent Mater 1985;1:197-9.