

# Comparative Evaluation of Marginal Accuracy of Metal Copings Fabricated using Direct Metal Laser Sintering, Computer-Aided Milling, Ringless Casting, and Traditional Casting Techniques: An *In vitro* Study

## Abstract

**Purpose:** The purpose of the study is to determine the amount of marginal discrepancy produced by Co-Cr copings fabricated using various fabrication methods which include direct metal laser sintering (DMLS), computer-aided milling, traditional casting, and ringless casting and compare the values obtained between each fabrication technique and to evaluate if the fabrication technique can produce prosthesis that is within the standards of clinical acceptance of marginal discrepancy.

**Materials and Methods:** Ten metal copings were fabricated by DMLS, computer-aided milling, traditional casting, and ringless casting. Marginal gap at the buccal, lingual, mesial, and distal areas was measured using silicone replica technique. A digital microscope was used to measure the silicone layer. Statistical analysis was done using one-way ANOVA test and *post hoc* Bonferroni test to test the difference between the fabrication method and categories of measured points, respectively.

**Results:** The values indicate that the marginal gap was least for the copings fabricated using ringless casting followed by traditional casting and DMLS. The widest gap was seen in copings fabricated using computer-aided milling. Analysis of results showed statistically significant difference between copings fabricated using computer-aided milling and traditional casting ( $P = 0.029$  and  $0.043$  – mesial and distal, respectively) and computer-aided milling and ringless casting ( $P = 0.002$  and  $0.001$  – mesial and distal, respectively). **Conclusion:** Even though the marginal gap was found to vary with the fabrication method, all measurements of marginal gap of all groups were well within the standard clinical acceptance of  $120 \mu$ .

**Keywords:** Computer-aided milling, direct metal laser sintering, marginal fit, ringless casting, traditional casting

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## Introduction

To achieve a clinically acceptable result for fixed dental prostheses (FDPs), the fit of the restoration is one important requisite for a good long-term prognosis. A study performed by Foster on 142 failed FDPs concluded that one important reason for this technical complication was an unacceptable fit.<sup>[1]</sup>

The adoption of automated systems has facilitated the development of a diverse range of fabrication methods, including the computer-aided milling and direct metal laser sintering (DMLS) system. The computer-aided milling involves mechanical processing of restorations by subtracting prefabricated blanks, while DMLS incorporates an additive manufacturing system that fabricates restorations by applying a laser beam (directed by the

data provided by a computer-aided drafting [CAD] file), which selectively melts metal powder to build up layers of solidified material.<sup>[2]</sup>

One of the common problems encountered with nonprecious alloys is the casting shrinkage due to the greater thermal contraction from higher solidification temperature. It is essential to achieve compensation for the shrinkage of the solidifying alloy by investment expansion.<sup>[3]</sup> Conventionally, steel rings have been most frequently used for investing and casting dental restorations. The metal casting rings are rigid and tend to restrict the setting expansion of investment in the radial direction. In addition, the thermal expansion of metal ring is less than that of investment. This causes a further constraint on thermal expansion of the investment during high-temperature casting. The use

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of ring liner compensates for the thermal expansion of the metal ring but only to a limited extent.<sup>[4]</sup>

Very few studies have provided a comparative assessment of metal copings based on Co-Cr alloys with regard to their marginal fits. Therefore, Co-Cr alloy coping was fabricated as part of this study using the latest computer-aided milling, DMLS, traditional casting, and ringless casting.

## Materials and Methods

Methods followed in the study will be discussed under the following headings:

- a. Preparation of model
- b. Fabrication of copings
- c. Grouping of samples
- d. Preparation of silicone replica
- e. Measurements of marginal fit.

### Preparation of model

In this study, a maxillary right canine typodont resin model was used. Tooth preparation was done with 1.0-mm circumferential chamfer finish line, 1.5-mm incisal height reduction, and a taper of 6 degrees with the help of a putty index [Figure 1]. Rounding of sharp edges was done at the end of the preparation.

### Fabrication of the copings

The resin tooth was first replicated with the help of silicone impression material (Aquasil Ultra LV and Aquasil Soft Putty and Light Body; Dentsply Caulk, Milford, DE, USA). Light body was injected around the prepared tooth, and a sectional tray loaded with putty was employed to make a single-stage impression. Die stone was then poured into the impression, and forty working models were obtained. Then, the working models were divided into four groups, ten samples for each group.

To fabricate DMLS copings, ten working models were scanned using a three-dimensional [3D] laser scanner (3Shape dental designers, Copenhagen, Denmark) [Figure 2], thus obtaining an indirect impression, and the data obtained were used to design the copings using a CAD software program (3Shape dental designers, Copenhagen, Denmark) [Figure 3]. The design was such that the coping will have a uniform thickness of 0.05 mm, and an allowance of 0.25 was provided 1 mm above the margin as die spacer. Then, the copings were fabricated using DMLS machine (EOSINT M 270; EOS GmbH, Krailling, Germany) by fusing Co-Cr powder (EOS SP2; EOS GmbH, Krailling, Germany). The ten copings obtained were labeled as Group 1.

For fabrication of copings using computer-aided milling, the same virtual coping design technique was used as stated above with the CAD software program. Ten copings were then milled from metal blanks (IMES-ICORE) using a milling machine (IMES-ICORE 550I) [Figure 4] and were labeled as Group 2.

For twenty models, die spacer (color spacer, HDC, Deccan Dental Depot Pvt. Ltd.) was applied 1-mm incisal to the margin of abutment teeth to a thickness of 25  $\mu$ . A dipping method was then used to fabricate 0.5-mm thick wax patterns. The wax patterns were then separated from the master die by attaching wax sprue. The sprue attached to the wax patterns was carefully attached to the sprue former.

Of the twenty, ten models were invested in a metal ring using Bellasun T phosphate-bonded investment material (BEGO, Germany) according to the manufacturer's recommendations. Burnout and casting processes were conducted on an induction casting machine. The castings

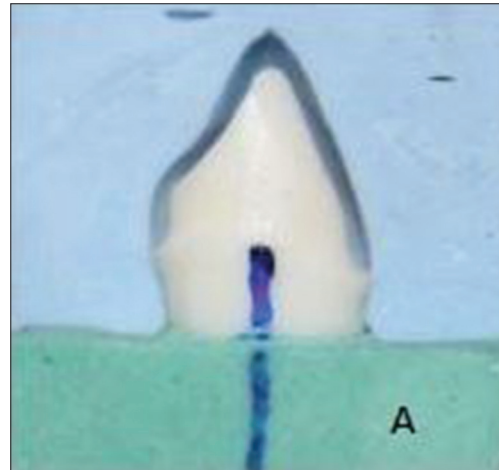


Figure 1: Prepared typodont with putty index



Figure 2: Three shape dental designer



Figure 3: Coping designed and saved in stereolithography file

were divested, and thus, copings fabricated using traditional casting were obtained which was labeled as Group 3.

The rest ten models were invested in a plastic ring using Bellasun T phosphate-bonded investment material (BEGO, Germany) according to the manufacturer's recommendations. Just like the first ten models, investing and burnout and casting processes were conducted, thus obtaining copings fabricated using ringless casting system. Group 4 was thus obtained. To ensure stable casting of the alloy, a high-frequency casting machine was used.

### Preparation of silicone replica

To measure the marginal gap, a silicone replica technique was used. For this, all the fabricated metal copings [Figure 5] were first filled with orange light body silicone to simulate the cement space and seated on the prepared typodont resin model and fitted by applying an even pressure of 50N on an electronic scale. Next, the metal copings were carefully separated, with the hardened light body silicone film, which represent the gap between the coping and the resin model. To facilitate easier measurement of the orange silicone layer and to keep bubbles from arising around the margin, a contrasting blue light body silicone was then added. After complete polymerization of the second layer of silicone, the copings were then carefully separated. As the light body silicone adherent to the model was often too thin to resist tearing or to maintain its shape, it was additionally covered with a strong heavy body silicone for stabilization. Finally, the replicated silicone was cut using a BP blade along the mesiodistal and labiolingual direction [Figure 6].

### Measurements of marginal fit

The sectioned samples were then examined under a digital microscope under  $\times 100$  magnification, and digital images were made [Figure 7]. The images were measured using imaging software (WeldCheck 2.0) (Analytical Research & Metallurgical Laboratories Pvt. Ltd., Bangalore, Karnataka, India), which was equipped to the digital microscope machine. A total of four points were considered, measuring the thickness of orange light body silicone, which represented the marginal discrepancy. Two points were considered mesiodistally and two points were considered labiolingually.

### Results

The mean marginal discrepancy of various test groups is shown in Table 1.

The values indicate that the marginal gap was least for the copings fabricated using ringless casting followed by traditional casting and DMLS. The widest gap was seen in copings fabricated using computer-aided milling. Tables 2 and 3 show multiple comparison of mean score difference between Group 1, Group 2, Group 3, and Group 4 on distal and mesial area, respectively.



Figure 4: Milling machine (IMES-ICORE 550)



Figure 5: Copings obtained grouped into four groups



Figure 6: Silicone replica of a single coping

Statistically significant difference was seen between copings fabricated using computer-aided milling and traditional casting ( $P = 0.029$  and  $0.043$ ) and computer-aided milling and ringless casting ( $P = 0.002$  and  $0.001$ ) at mesial and distal surfaces, respectively.

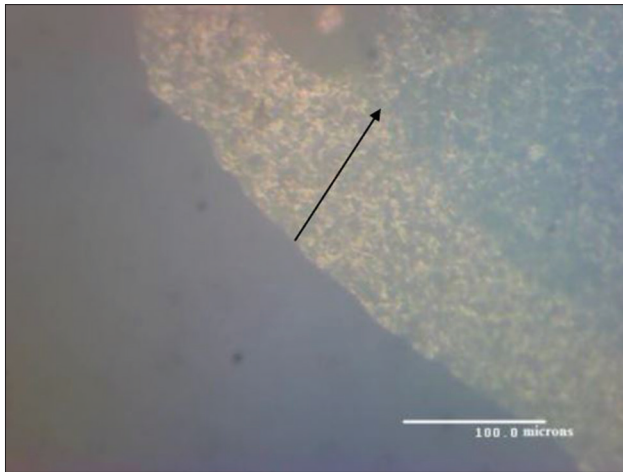


Figure 7: Measurement of the marginal area silicone thickness by digital microscopy (x100)

## Discussion

In the past 50 years, the field of dentistry has witnessed remarkable changes. Many of these changes in material and technologies have been rewarding and with each change have come opportunities for improving the quality of care. Advent of automated system in fabrication of dental prosthesis is one of them.

By the introduction of phosphate-bonded investment, the use of ringless casting technique has been made possible, which is commonly used currently for fabrication of fixed prosthesis and cast partial dentures. The ability of these investments to withstand high temperature during casting (refractoriness) is due to refractory filler and binder content in them.

The present study attempts to evaluate the marginal accuracy of cobalt-chromium copings fabricated using DMLS, computer-aided milling, traditional casting, and ringless casting and comparatively analyze the marginal discrepancy.

There is no clearly defined criterion on the amount of gap that can be acceptable clinically. According to the American Dental Association specification no. 8, the thickness of the luting cement for a bonded prosthesis should be  $<20 \mu$ . It is difficult to fabricate a casting with such minimal marginal gap. Various literature show wide range of clinically acceptable marginal gap, ranging from a gap of  $200 \mu$  suggested by Gulker<sup>[5]</sup> to a gap of  $50\text{--}75 \mu$  suggested by Hung *et al.*<sup>[6]</sup> According to them, a marginal gap  $<80 \mu$  was difficult to detect clinically. McLean and von Fraunhofer<sup>[7]</sup> reported a maximum allowable marginal gap of  $120 \mu$ . This criterion is referenced in most of the recent studies done to evaluate the marginal discrepancy of cast restorations.

In this study vertical marginal gap, the discrepancy in vertical direction was taken as the basis for the assessment of fit of the crowns. The reason being, vertical discrepancies are

**Table 1: Mean marginal discrepancy of various test groups (unit:  $\mu\text{m}$ ,  $n=10$ )**

Area viewed	Mean marginal discrepancy			
	Group 1 ( $\pm$ SD)	Group 2 ( $\pm$ SD)	Group 3 ( $\pm$ SD)	Group 4 ( $\pm$ SD)
Buccal	101.10 $\pm$ 7.35	103.89 $\pm$ 8.41	98.15 $\pm$ 6.69	95.62 $\pm$ 3.96
Lingual	108.09 $\pm$ 13.59	113 $\pm$ 13.35	105.16 $\pm$ 14.1	101.6 $\pm$ 8.06
Mesial	102.72 $\pm$ 5.11	109.47 $\pm$ 11.93	100.06 $\pm$ 4.14	97.24 $\pm$ 3.17
Distal	100.42 $\pm$ 3.09	111.48 $\pm$ 8.84	103.74 $\pm$ 4.65	100.42 $\pm$ 3.09

The maximum discrepancy is observed in the lingual area compared to all other three areas. SD: Standard deviation

**Table 2: Multiple comparison of mean score difference between Group 1, Group 2, Group 3, and Group 4 on distal area (unit:  $\mu\text{m}$ ,  $n=10$ )**

Type	Mean difference	$P^*$
Group 1 versus Group 2	-5.39	0.32
Group 1 versus Group 3	2.34	1.00
Group 1 versus Group 4	5.66	0.26
Group 2 versus Group 3	7.74	0.043 <sup>†</sup>
Group 2 versus Group 4	11.05	0.001 <sup>†</sup>
Group 3 versus Group 4	3.31	1.00

\*By *Post hoc* Bonferroni test, <sup>†</sup>Significant two-tailed,  $P<0.05$

**Table 3: Multiple comparison of mean score difference between Group 1, Group 2, Group 3, and Group 4 on mesial area (unit:  $\mu\text{m}$ ,  $n=10$ )**

Type	Mean difference	$P^*$
Group 1 versus Group 2	6.748	0.22
Group 1 versus Group 3	2.667	1.00
Group 1 versus Group 4	5.481	0.53
Group 2 versus Group 3	9.415	0.029 <sup>†</sup>
Group 2 versus Group 4	12.229	0.002 <sup>†</sup>
Group 3 versus Group 4	2.81	1.00

\*By *Post hoc* Bonferroni test significant two-tailed,  $P<0.05$ ,

<sup>†</sup>Significant two-tailed,  $P<0.05$

least liable to correction after crown fabrication, as indicated by Holmes *et al.*<sup>[8]</sup> Horizontal discrepancies such as crown overhang can be corrected to some extent intraorally, whereas, a vertical marginal gap can only be closed with luting cement, which is prone to dissolution. For this reason, vertical marginal gap is more clinically significant and should be considered as the most crucial factor in crown margin evaluation.

This article followed silicone replica technique. Lombardas *et al.*<sup>[9]</sup> in their study, used a magnification of 100x to visualize the discrepancy of fit of the crowns. Laurent *et al.*<sup>[10]</sup> stated that, with the appropriate use of silicone replicas, accurate measurement of the actual size of cement thickness can be done from any position (cervical/axial/occlusal).

The results of this study, however, differ from some of the previous studies. For instance, Park *et al.*<sup>[2]</sup> used a digital microscope and silicone replica method. According to them,

the comparison of fit of the copings showed that the gap showed by DMLS was more than that of computer-aided milling and traditional casting, and the measurement of marginal discrepancy obtained was slightly lower than the current study. In contrast, Örtorp *et al.*,<sup>[1]</sup> in their study, showed a stereomicroscope and digital photograph for the evaluation of marginal and internal gap of CO-Cr three unit bridges for posterior teeth. The results showed that DMLS showed a narrower gap than conventional casting. The widest gap was seen with bridges obtained from CAD/computer-aided manufacturing. However, a study, conducted by Jung,<sup>[11]</sup> showed similar result as the current study. They used a stereomicroscope under  $\times 200$  magnification to measure the marginal and internal gap of Co-Cr metal coping. Their results showed that marginal and internal gaps were found to be least for copings fabricated using traditional casting followed by copings fabricated using 3D printing and milling process. Singh *et al.*,<sup>[3]</sup> in their study, measured the marginal integrity of metal copings fabricated using ringless and closed ring casting technique. Their comparison showed that the marginal accuracy of ringless casting technique was superior to that of closed ring casting technique, which is similar to the present study.

In this study, the mean marginal gaps measured were 103.08 (7.29)  $\mu$ , 109.46 (10.63)  $\mu$ , 101.78 (7.34)  $\mu$ , and 98.72 (4.57)  $\mu$  in order of DMLS, computer-aided milling, traditional casting, and ringless casting. The values indicate that the marginal gap was least for the copings fabricated using ringless casting followed by traditional casting and DMLS. The widest gap was seen in copings fabricated using computer-aided milling. This variation in the measurements may be due to inadequate precision of the scanner that reads the abutment or inadequacy in precision of the machine that will process the CAD data. According to Persson *et al.*, a scanner using laser tends to make sharp edge rounder.<sup>[12]</sup> Furthermore, the thermal gradient in the powder bed in DMLS can induce thermal stress which will lead to warpage and distortion of the fabricated prosthesis.<sup>[13]</sup> Comparing the values obtained at various surfaces of the same casting, the lingual surface showed slightly greater values of marginal gap than other surfaces of all groups. A bar diagram with the mean discrepancy obtained in the lingual area is shown in Figure 8. In this study, crowns were seated on master die using finger pressure. Even though this method simulates the cementation of fixed restoration clinically, it should be emphasized that the use of finger pressure is variable. This could be one of the reasons for variation in measurement in the lingual surface. In addition, factors such as making of the impression and shrinkage and stress relaxation of inlay casting wax also might have contributed to the increased marginal discrepancy at the lingual surface.

However, analysis of the results of this study showed statistically significant difference between copings fabricated using computer-aided milling and traditional

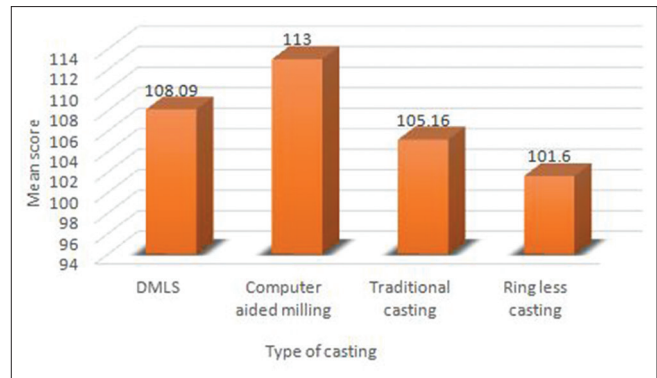


Figure 8: Bar diagram showing mean value of marginal discrepancy at lingual area

casting ( $P = 0.029$  and  $0.043$ ) and computer-aided milling and ringless casting ( $P = 0.002$  and  $0.001$ ) at mesial and distal surfaces, respectively. Even though no significant difference was observed in marginal discrepancy between the four groups, all measurements of marginal gap were well within the standard clinical acceptance of  $120 \mu$ , thus indicating a better fit across all groups. However, the findings of this study are comparable to some of the previous studies.<sup>[2,9,14-16]</sup>

The main limitation of this study is that only vertical gaps were examined and no horizontal planes were measured, as performed by others. In addition, the study was *in vitro*, which cannot simulate oral conditions, and marginal gap was evaluated to assess precision of restoration, and the internal fit was not considered.

Input of information and accuracy of processing influence the fit of prosthesis fabricated through automated system. Errors arising from such processes are likely to cause an increase in marginal gap. Based on the results obtained from this study, the digital method does not seem to be a legitimate alternative to the traditional method. However, because the clinical acceptance of a crown prosthesis requires more than simply an acceptable vertical marginal gap, further studies are required to assess the remaining marginal parameters, as outlined by Holmes *et al.*<sup>[8]</sup>

## Conclusion

Within the limit of this study, the marginal discrepancy of Co-Cr copings fabricated using DMLS, computer aided milling, traditional casting, and ringless casting were found to be within the range of clinical acceptance ( $<120 \mu$ ). On comparison, the copings fabricated using ringless casting showed least marginal discrepancy followed by traditional casting followed by DMLS. Copings fabricated using computer-aided milling showed the greatest marginal gap in comparison with the other test groups. Therefore, the result of this study implies the superiority of conventional casting systems over automated systems, and hence, further improvement of automated systems is warranted.

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## Conflicts of interest

There are no conflicts of interest.

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