Comparison of the marginal accuracy of metal copings fabricated by 3D-printed resin and milled polymethyl methacrylate – An *in vitro* study

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Abstract

Computer-aided design/computer-aided manufacturing (CAD/CAM) systems have gained popularity over the traditional laboratory procedures in dentistry. In the conventional metal casting technique by burnout of a pattern, instead of using a wax pattern (which has several disadvantages), milled polymethyl methacrylate (PMMA) and 3D-printed resin patterns can also be used. The objective of the study was to assess and compare the marginal accuracy of single-crown cobalt–chromium (Co-Cr) metal copings fabricated using milled PMMA and 3D-printed resin patterns. Digital designing was done for metal coping on a prepared typodont mandibular molar using 3Shape Dental Design software. Standard Tessellation Language document of CAD design was used to fabricate 3D-printed resin patterns (Sprintray 3D printer) and milled PMMA patterns (CAD/CAM milling machine CoriTEC). A total of ten Co-Cr copings were casted, of which five belonged to Group A: 3D-printed resin and the other five to Group B: milled PMMA. The copings were assessed for marginal fit at eight different points using a stereomicroscope. Statistical analysis was done using an independent *t*-test. The *t*-test revealed a significant difference between the mean marginal gap values of the two groups, with the marginal gap values for the 3D-printed resin group (82.21 ± 15.26 μm) being lesser than that of the milled PMMA group (106.75 ± 12.76 μm). The marginal accuracy of copings fabricated using 3D-printed resin patterns was superior to that of copings fabricated from milled PMMA patterns.

Key words: 3D printing resin, innovation, marginal accuracy, milled PMMA, polymethyl methacrylate

INTRODUCTION

Marginal fit is the space between the margin of the prepared tooth and the dental restoration. It plays a vital role in the longevity of the tooth and the restoration. Inaccurate marginal fit can lead to microleakage, which can result in secondary caries, sensitivity, dissolution of the luting cement, and ultimately failure of the restoration.[1,2] The lost-wax technique was given by Taggart in the early 1900s, in which the fabrication of metal crowns and other fixed dental restorations was made possible. In this technique, a wax-up replicating the size and shape of the final dental prosthesis is made on the study cast of the prepared tooth. The wax pattern is taken out from the cast,

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encased in an investment mold, burned out, and replaced with the required material.[3] However, it is a highly technique-sensitive procedure, relying majorly on the skill of the dental technician as the wax can easily get distorted due to various reasons (such as its delicate nature, release of internal stresses or elastic memory, thermal sensitivity, and high coefficient of thermal expansion) which can lead to inaccurate final restoration.[4-6] For example, when the wax pattern is removed from the die, it already leads to a misfit of 35 μ due to wax distortion.[7] Hence, different materials such as resins were tried to find better alternatives to wax as a pattern for metal restorations.[8]

Computer-aided design and computer-aided manufacturing (CAD/CAM) was introduced as a completely digital workflow in dentistry. It can be done in two ways: by subtractive method, in which the restoration is milled from a preformed block of material; or by additive method, in which the restoration is built by layer-by-layer addition of material. Examples of additive methods being used in dentistry are 3D printing, stereolithography, and selective laser sintering. Metal structures can be created through 3D printing, either indirectly through the use of burnout resins or waxes in a lost-wax technique, or directly in metals or metal alloys. The advantage of printing in resin/wax and then employing a classic casting method over direct 3D printing of metals is that it requires far less postprocessing and is more economical.[9,10]

Restorations made using CAD/CAM results in more accurate and uniformly formed prostheses as they are made either from preformed blocks or by machined incremental pattern.[11-17] The final product does not need reshaping, and the whole process saves a lot of time and labor.[18,19] Given the simplicity of digital designing, CAD/CAM should be preferably used over the manual technique.[20] However, there are certain disadvantages of the CAD/CAM systems as well. The finite resolution of the scanning systems can result in slightly rounded edges. The point clouds generated during scanning are turned into a smooth and continuous surface using a CAD software program, which can result in certain internal imperfections. There can be interfering contacts at the incisal/occlusal edges, which can cause microleakage if they occur at the margins.[19,21]

Many authors have compared the marginal fit of metal restorations made with conventional methods and CAD/CAM methods. However, to the best of our knowledge, no study has been done comparing the marginal fit of metal copings fabricated using milled polymethyl methacrylate (PMMA) and 3D-printed resin burnout techniques. Moreover, with the ever-constant need to find better technology, the aim of this study was to compare the marginal fit of cobalt–chromium (Co-Cr) copings fabricated from 3D-printed resin patterns and milled PMMA patterns. The null hypothesis was that there is no difference between the marginal fit of metal copings fabricated using 3D-printed resin and milled PMMA patterns.

MATERIALS AND METHODS

A right mandibular first molar on a typodont model was prepared with a 2-mm shoulder margin all around. The typodont model was sprayed with a titanium dioxide CAD/CAM spray, and it was then scanned by the laser laboratory scanner (Medit T300). The scanned data were transferred to 3Shape, which is a CAD design software. Digital designing was done for Co-Cr coping of the thickness of 0.5 mm using 3Shape Dental Design software [Figure 1]. The final design was converted into a Standard Tessellation Language (STL) file [Figure 2]. Ten patterns were then fabricated from the same STL file, of which five belonged to milled PMMA (made using imes-icore milling machine) and five belonged to 3D-printed resin (fabricated using SprintRay 3D printer).

The ten patterns were then immediately casted, Group A was assigned to copings made out of 3D-printed resin patterns and Group B to those made from milled PMMA patterns. Wax sprues were attached to all the patterns, following which they were invested. After burnout of the pattern in a preheated furnace, casting was done using Co-Cr alloy in a casting machine.

After the casting was over, a separating disk was used to cut the sprues from the copings. The copings were finished using metal trimming bur to remove any irregularities on the surface which could have occurred during casting. The copings were finally abraded with 50 µm Al_2O_3 at a pressure of 325 kPa. The copings were assessed for marginal fit at eight different points (mid-buccal, mesiobuccal, distobuccal, mid-distal, mid-mesial, mid-lingual, mesiolingual, and distolingual [Tables 1 and 2]) using a stereomicroscope (Lawrence and Mayo, India Pvt. Ltd.) [Figures 3 and 4].

The data were analyzed using version 23 of IBM-SPSS (Statistical Package for the Social Sciences, IBM Corporation, Chicago, USA). For each group, the standard deviations and mean values were calculated, and an independent *t*-test was performed to compare the mean differences between the two groups.

RESULTS

The *t*-test revealed a significant difference ($P = 0.017$) between the mean marginal gap values of the two groups, wherein the mean marginal gap of the 3D-printed resin group (82.21 ± 15.26 µm) was lesser than that of the milled PMMA group (106.75 ± 12.76 µm) [Table 3 and Figure 5].

DISCUSSION

The aim of the study was to evaluate and compare the marginal accuracy of Co-Cr copings fabricated using the burnout of 3D-printed resin and milled PMMA patterns.

The results showed a significantly better marginal fit of copings fabricated using 3D-printed resin patterns. Hence, the null hypothesis that there is no difference between the marginal fit of metal copings fabricated using 3D-printed resin and milled PMMA patterns was rejected.

Milling has a number of advantages, the most important of which is its high speed (crown patterns can be created within 7 min) and output rate, which lowers costs.[22] The internal accuracy of the restoration is dependent on the size of the smallest cutting instrument, which is one of the disadvantages. As a result, if the design of the pattern is smaller in certain places than the tool, the internal accuracy will be compromised. Furthermore, the cutting tools are unsuccessful at producing sharp internal angles. This problem could be solved by increasing the spacer thickness in the CAD/CAM design, or by using a handpiece to remove the created interfering areas. However, both of these approaches increase the gap between the tooth and the restoration.[23] Cutting tool wear occurs when milling hard-to-machine materials like metals. Other issues are heat and noise generation, and the amount of nonrecyclable waste generated. Milling can waste up to 95% of the material, whereas additive techniques can generate 40% less waste, with up to 96% of it being recyclable.

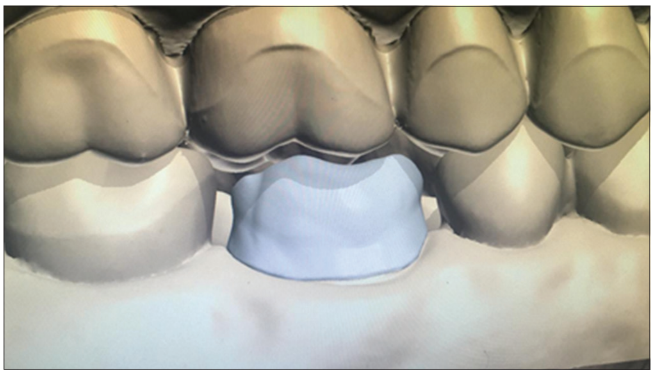

Figure 1: CAD design of the coping. CAD: Computer-aided design

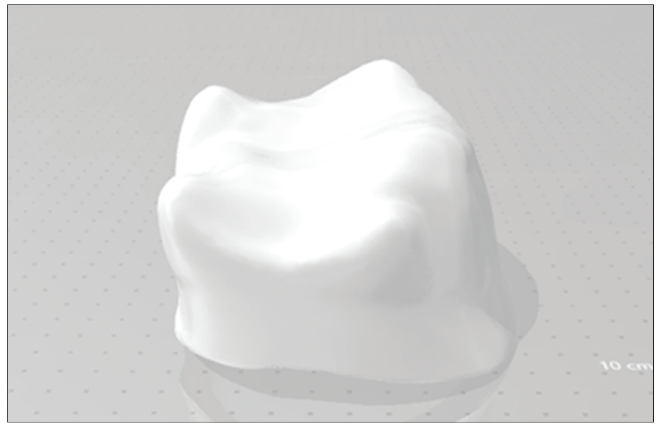

Figure 2: STL file of the coping. STL: Standard Tessellation Language

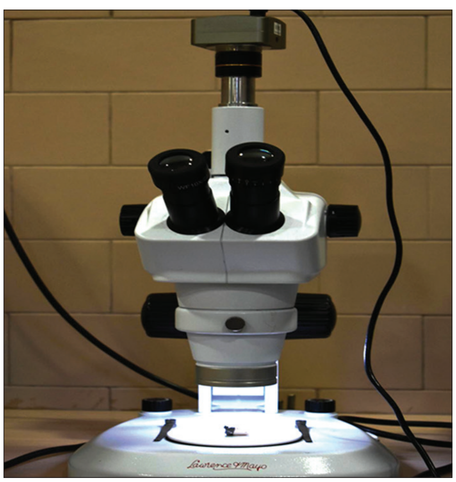

Figure 3: Metal coping on typodont tooth focused under stereomicroscope

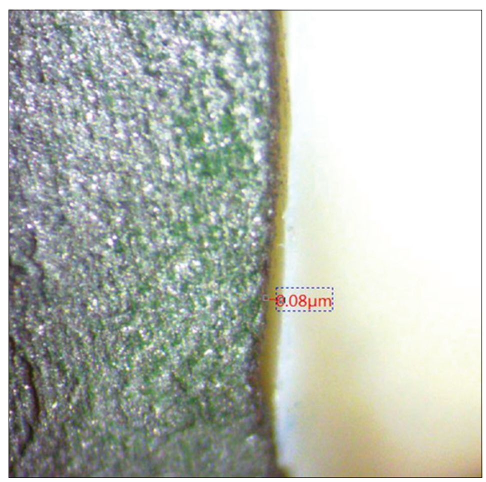

Figure 4: Marginal discrepancy shown by stereomicroscope

Table 1: Values for marginal gap (μm) of each sample of metal copings fabricated from three-dimensional printed resin at eight different points

Sample number	Marginal gap (μm)							
	Buccal	Lingual	Mesial	Distal	Mesiobuccal	Mesiolingual	Distobuccal	Distolingual
1	20	70	80	90	30	50	80	30
2	130	190	30	70	100	80	100	70
3	50	150	100	190	40	70	90	90
4	110	80	60	80	140	90	60	50
5	160	70	40	120	30	60	130	80
Mean	94±57.7	112±54.95	62±28.63	110±48.47	68±49.69	70±15.81	92±25.88	64±24.08

Table 2: Values for marginal gap (µm) of each sample of metal copings fabricated from milled polymethyl methacrylate at eight different points

Sample number	Marginal gap (µm)							
	Buccal	Lingual	Mesial	Distal	Mesiobuccal	Mesiolingual	Distobuccal	Distolingual
1	60	110	60	110	100	30	150	210
2	100	190	220	40	30	100	60	90
3	20	130	100	150	120	40	60	100
4	210	130	100	80	100	80	60	130
5	190	140	110	180	100	80	110	90
Mean	88±25.88	136±72.66	90±77.45	98±49.69	106±66.18	98±20.49	126±47.22	112±39.62

Table 3: Mean marginal gap values (µm) for three-dimensional printed resin and milled polymethyl methacrylate groups

Sample number	Marginal gap (µm)	
	3D-printed resin	Milled PMMA
1	56.25	103.75
2	96.25	103.75
3	88.83	90.00
4	83.75	111.25
5	86.00	125.00
Total mean	82.21±15.26	106.75±12.76
P	0.026	

Results show that the mean marginal gap values were significantly (*P*=0.026) higher for metal copings fabricated using milled PMMA. PMMA: Polymethyl methacrylate

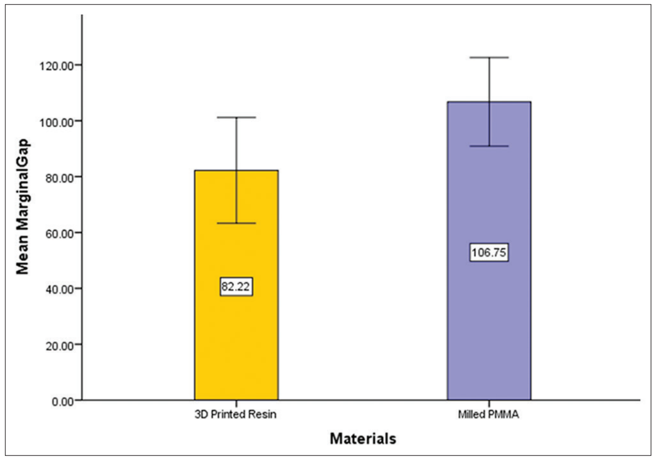

Figure 5: Bar graph showing mean marginal gap values for 3D-printed resin and milled PMMA groups. PMMA: Polymethyl methacrylate

This can reduce overall costs.[24,25] Printers in the additive fabrication technique may differ in how the layers are added to make prostheses. Undercuts can be replicated with this process, and less raw material is wasted.[26] However, additive techniques, like every other system, can have drawbacks, such as steps on the surface of the finished product due to the increment of one layer over the other, nonuniform shrinkage, and extensive postprocessing of porous layers.[27,28] Increasing precision has been shown to slow down production speed.[29] Other factors that can potentially affect the accuracy of the printed restoration are the model of the 3D printer used and the thickness of each additive layer of the resin.[30]

The present study found superior marginal fit in restorations fabricated by 3D-printed resin patterns than those fabricated from milled PMMA patterns. This could have been due to the distortion of PMMA because of the heat generated during milling, or due to the limitations in the sizes of the cutting tools used for milling.[31]

The marginal gap of metal copings was calculated using direct microscopy, which is a completely nondestructive process. Results are repeatable, and the marginal difference is measured in an infinite number of points. Furthermore, it allows for direct visualization and measurement of the vertical marginal misfit without the use of cement, elastomeric light body, or sectioning of the specimen. The omission of cement was considered important because cement itself can influence margin discrepancy. Other approaches with lengthy and numerous procedures are more expensive, time-consuming, and less precise than this technique. In direct microscopic view, however, the horizontal marginal gap cannot be determined.[32]

The mean marginal distance of copings in this study was <120 μ,[33] indicating that CAD-CAM restorations produced using either of the methods would be clinically acceptable.

Limitations and future scope

Intraoral environment was not simulated in the current study. A distinct margin was made on the master die, a preparation that is not always seen in routine practice. The copings were also not subjected to thermocycling. Clinical investigations on the effects of aging of the specimens are recommended. Furthermore, horizontal marginal discrepancy was not considered in this study.

CONCLUSION

1. Metal copings fabricated using 3D-printed resin have a superior marginal fit than those fabricated using milled PMMA
2. Co-Cr copings fabricated using either milled PMMA

or 3D-printed resin patterns have marginal fit falling under the clinically acceptable range.

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Conflicts of interest

There are no conflicts of interest.

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