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ORIGINAL ARTICLE

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

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Abstract Accuracy of the fit of the restoration has always remained as one of the primary factors in determining success of the restoration. A well fitting restoration needs to be accurate both along its margins and internal surface. This study was conducted to comparatively evaluate the marginal gap and internal gap of cobalt–chromium (Co–Cr) copings fabricated by conventional casting procedures and with direct metal laser sintering (DMLS) technique. Among the total of 30 test samples 10 cast copings were made from inlay casting wax and 10 from 3D printed resin pattern. 10 copings were obtained from DMLS technique. All the 30 test samples were then cemented sequentially on stainless steel model using pressure indicating paste and evaluated for vertical marginal gap in 8 predetermined reference areas. All copings were then removed and partially sectioned and cemented sequentially on same master model for evaluation of internal gap at 4 predetermined reference areas. Both marginal gap and internal gap were measured in microns using video measuring system (VMS2010F). The results obtained for both marginal and internal gap were statistically analyzed and the values fall within the clinically acceptable range. The DMLS technique had an edge over the other two techniques used, as it exhibited minimal gap in the marginal region which is an area of chief concern.

Keywords Marginal gap · Internal gap · 3D printed resin pattern · Direct metal laser sintering (DMLS)

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Introduction

The prime goal of any prosthodontic treatment is to provide the patient with precisely fitting restorations or prosthesis. In case of fixed prosthodontics marginal gap and internal gap are the essential factors determining the long term success of the prosthesis [1–6]. Based on literature review the acceptable vertical marginal gap ranges between 10 and 160 µm and internal gap ranges between 81 and 136 µm [7–9].

Pattern formation employ materials like inlay casting wax, autopolymerizing resins, light cured resins. Distortion of wax pattern like shrinkage due to relaxation of internal stress contributes to detrimental effects on cast restoration [10–13]. Resins were recommended to overcome the shortcomings of wax as pattern forming material. Autopolymerising resins offer strength, rigidity, and dimensional stability if immediate investment is not possible. However the disadvantage of this material is its polymerization shrinkage. Thus to overcome this, newer light polymerized dimethacrylate modeling resins were used which can be manipulated with increased precision and stability after light polymerization [14–16]. Recently technologies like stereo lithography (SL), selective laser sintering (SLS) and an additive prototyping technique (3D printing) is being used to design and then print a wax pattern or a resin pattern in a layer by layer manner to result in three dimensional objects which has good dimensional stability.

Base metal alloys have demonstrated good clinical performance and resistance to permanent intraoral deformation in most clinical situations. Previously Co–Cr alloys were primarily used for RPD frameworks [17, 18]. Currently they are also used more commonly than Ni–Cr alloys for fixed prosthesis. Electrochemical studies show that Co–Cr alloys are more resistant to corrosion than Ni–Cr alloys. Nickel based alloys also have a greater sensitization potential than cobalt chromium alloys, whereas Co–Cr alloy allergies are rare [19–22]. The absence of allergic response and its rigidity made Co–Cr to be selected as material of choice for this study.

Difficulties encountered during casting of base metal dental alloys limit their use. Application of these alloys might be enhanced if casting procedure is completely eliminated and new techniques are used. Direct metal laser sintering (DMLS) is a new technique that replaces conventional metal casting procedures [23–25]. DMLS is a CAD/CAM based technique in which frame works and metal copings can be designed and fabricated using cobalt chromium. This hi-tech process is sometimes described as 3D printing because it builds up each frame work in a series of successive thin layers (0.020 mm). A high power laser beam is focused on to a bed of powdered metal (Co–Cr) and these areas fuse into thin solid layer and another layer of powder is then laid down over this and the next slice of frame work is produced and fused with the first until framework or coping is finished [26].

First a structure light optical scanner is used to scan the model for which we need a coping or a framework. The registration and triangulation algorithms are used to reconstruct the scanned data into STL file (Standard Template Library-virtual model consisting in mesh of triangles). Then we obtain a virtual triangular solid model. In the coping design process, the first part is to find the margin lines of the prepared abutment teeth followed by programming the desired spacer thickness. Then the non uniform offsetting and shelling algorithms is proposed to create the coping shell model with variable thickness. The completed STL data of the restoration are fed to the CAM bridge software from where the data are forwarded to the building chamber of the DMLS machine which produces the final copings and frameworks.

Statement of Problem

Precise marginal adaptation is necessary to achieve better mechanical, biological and esthetic prognosis of the restorations. Inaccurate marginal fit is responsible for plaque retention, micro leakage and cement breakdown and permits penetration of bacterial components along with the saliva through these gap. Poor internal fit of a coping can increase the thickness of the cement and thus influence the mechanical stability of dental restorations. The minimization of crown marginal gap and internal gap is an important goal in prosthodontics.

Materials and Method

A standardized CNC machined stainless steel model and a counterpart were made. The model used in this study had a deep chamfer margin with 6° axial wall taper and 10° occlusal inclination (Figs. 1, 2). A single stage impression of the master model with polyvinylsiloxane was made and a master die was made using Type IVdie stone. This master die was used for fabricating all the 30 copings used in this study. Master die was scanned by 3 shape D700 scanner for making 3D printed resin patterns of 0.5 mm thickness (10 nos.) and the same die was scanned with lava ST scanner for obtaining direct metal copings of 0.5 mm thickness(10 nos.). Then the die was used for making wax patterns (10 nos.) in the conventional manner after application of die hardener, die spacer and die lube. A trough was designed around the base of the tooth preparation section (Fig. 3a) to collect the overflowing excess inlay wax which escapes through the slits (Fig. 3b) made in the counterpart while fabricating the wax pattern. The pressure that builds in during fabrication of wax pattern dissipates through slits in the master model former assembly and the excess wax reaches the trough via the slits and gets collected in the trough in the base of the model thus resulting in wax patterns of equal thickness of 0.5 mm (Figs. 4, 5).

Twenty samples obtained using inlay casting wax pattern and 3D printed resin pattern were subjected to casting procedures, divested, sandblasted and steam cleaned and labeled as (G1) which were cast copings obtained from inlay casting wax pattern (10 nos.) and (G2) which were cast copings obtained from 3D printed resin pattern (10 nos.). 10 copings for third group were obtained directly

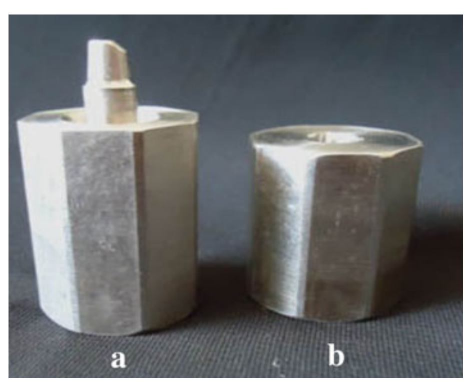


Fig. 1 **a** Axial view of custom-made stainless steel model, **b** stainless steel former assembly

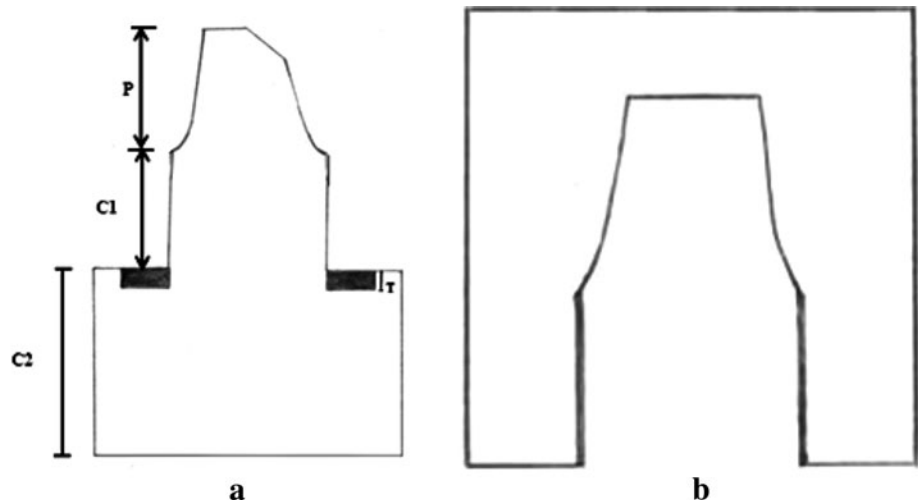


Fig. 2 **a** Line diagram of custom-made stainless steel model tooth preparation section-(*P*), cylindrical section-(*C1*), trough around the cylindrical section-(*T*), octagonal base-(*C2*) **b** stainless steel former assembly

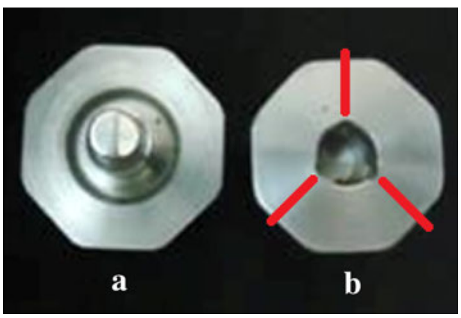


Fig. 3 **a** Occlusal view of custom-made stainless steel model, **b** stainless steel former assembly showing 3 vertical slits

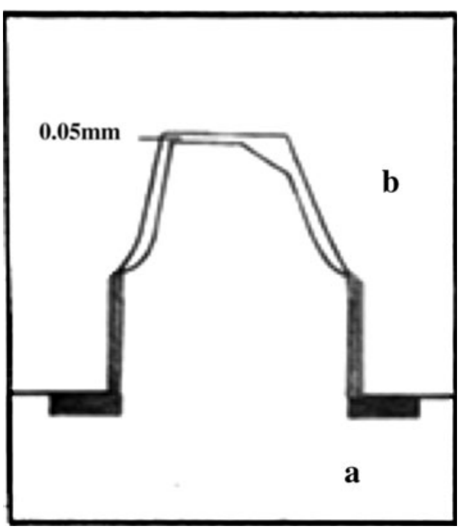


Fig. 4 **a** Line diagram of custom made stainless steel model, **b** stainless steel former assembly in apposition

Fig. 5 Fabrication of wax pattern

from DMLS technique and they were sandblasted and steam cleaned and labeled (G3) (Fig. 6) test samples.

All the test samples of each group was coated on the internal surface with a thin layer of pressure indicating paste (fit checker) and seated on stainless steel master die, sequentially under 2 kg load which was placed on a platform mounted on the vertical arm of an surveyor for 2 min to simulate a coping cemented in the oral condition. Fit checker was used because it was easy to be removed from inner surface without damaging the inner surface of the copings. After setting, the assembly was removed from the surveyor and excess paste was removed. The assembly was placed under video measuring system (VMS2010F) for evaluation of vertical marginal gap. Mid points of the each octagonal base marked on the model and corresponding 8 predetermined reference points were used for vertical marginal gap evaluation (Fig. 7). The octagonal shape of the master model base, prevented the model from moving while measuring of vertical and internal gaps. Copings were then removed and the fit checker paste on the inner surface was removed. The copings were partially sectioned as shown in (Fig. 8a) leaving a band of metal coping which

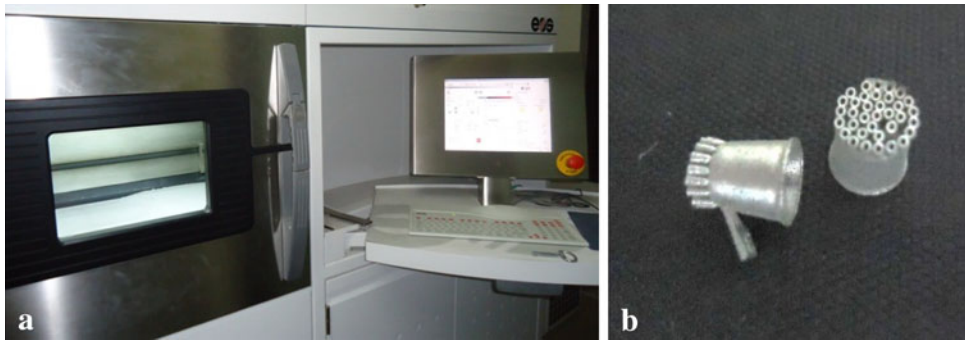


Fig. 6 **a** DMLS machine. **b** DMLS copping

Fig. 7 Schematic representation of 8 predetermined reference areas to be measured for vertical marginal gap

involves the entire margin. This partially sectioned coping was again reseated in the same position onto the stainless steel master model (Fig. 8c). The presence of occlusal bevel and the part of coping in direct contact with master model 1 mm above the chamfer margin helps to reorient the coping in the previous position. The same 2 kg load was applied which was placed on the platform table mounted on the vertical arm of surveyor and excess paste was removed after setting and internal gap was measured at 4 predetermined points (Fig. 8c) marked on the model internal surface using a marker. This procedure was done sequentially for all the samples and readings obtained were noted. All the copings were reoriented on the same stainless steel master model. This was done to test the discrepancy in the test samples with differences in the fabricating techniques only. The results obtained for both marginal and internal gap were tabulated and statistically analyzed. All statistical calculations were performed using Microsoft Excel (Microsoft, USA). The SPSS (SPSS for Windows 10.05, SPSS Software Corp. Munich, Germany) software package was used for statistical analysis. '*T*' test was used to compare the mean values of each test groups and a P value <0.05 was considered statistically significant.

Results

The mean values of marginal and internal gap were tabulated (Table 1).

The vertical marginal gaps of the copings obtained by three different fabrication techniques methods were statistically significant to each other. The copings obtained from DMLS technique showed statistically significant minimum value followed by cast copings obtained using 3D printed resin pattern. The cast copings obtained from inlay casting wax pattern showed maximum vertical marginal gap. The results of the internal gap present between the coping and the master model showed statistically significant difference between cast copings obtained using inlay casting wax and cast copings obtained using 3D printed resin pattern. Cast copings obtained from 3D printed resin pattern and copings obtained from DMLS technique also showed statistical significance. But there was no statistical difference between cast copings obtained from inlay casting wax and copings obtained using DMLS technique.

Discussion

Ideally, cemented crown margins meet prepared tooth margins in perfect non-detectable junctions. In actuality clinical perfection is equally difficult to achieve and difficult to verify. Hence minimal marginal gap is nominally approximately acceptable· The term marginal gap and internal gap do not have single definition. Holmes et al., who established several gap definitions according to contour difference between the crown and tooth margin, states that "the perpendicular measurement from inner surface of casting to the axial wall of preparation is called internal gap, and the same measurement at the margin is called marginal gap". Increase in internal space thickness will lead to compromised retention. But the essence of concern is the space existing between the restoration and tooth preparation margin where both meet the oral environment, as gap measurement at the margin quantify the fit [27, 28].

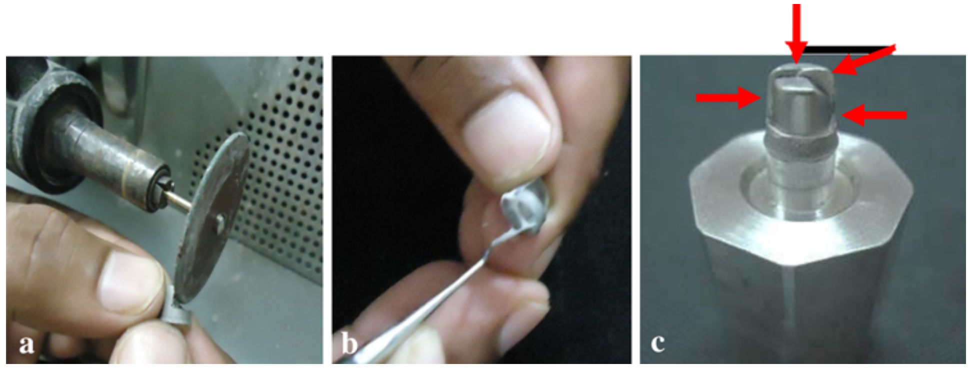
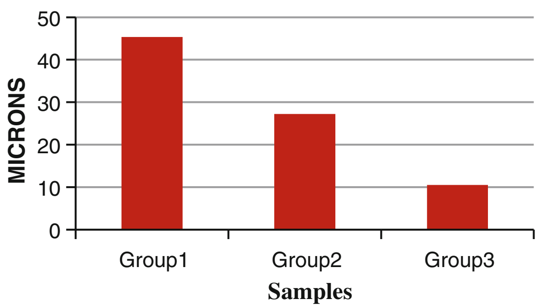


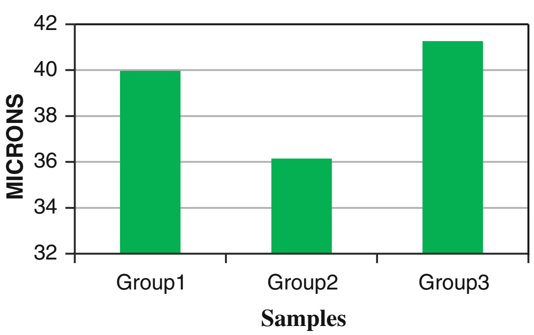
Fig. 8 **a** Sectioning of Co–Cr coping before internal gap evaluation. **b** Pressure indicating paste applied on the inner aspect of Co–Cr coping. **c** Co–Cr coping seated on master model after partial sectioning

Table 1 Showing mean vertical marginal and internal gap

Test groups	Group 1	Group 2	Group 3
Marginal gap (μm)	45.36	27.22	10.52
Internal gap (μm)	39.97	36.15	41.22



Graph 1 Comparison of mean vertical marginal gap values of three groups (G1, G2 and G3)



Graph 2 Comparison of mean internal gap values of three groups (G1, G2 and G3)

Many studies have been done to improve the fit of the cast restoration. Multiple protocols to minimize errors and yield best internal and marginal fit of the cast restoration also had been suggested [29–36]. However very few studies have reported about obtaining metal copings directly using CAD/CAM technique using Co–Cr alloys which has no nickel in its composition which has greater sensitization potential [37]. Studies comparing discrepancies of the copings made using Co–Cr alloy using conventional casting and DMLS is also lacking.

The basic data obtained in this study shows a mean vertical marginal gap of 45.36 μm for cast copings obtained from inlay casting wax pattern (G1), 27.22 μm for cast copings obtained from 3D printed resin pattern (G2)and 10.52 μm for copings obtained using DMLS technique (G3, Graph 1).

The reason for comparatively high vertical marginal gap 45.36 μm for (G1) may be due to the shrinkage and stress relaxation of the inlay casting wax. The mean vertical marginal discrepancy of cast copings obtained from 3D printed resin pattern (G2) is 27.22 μm, Magix software which compensates for polymerization shrinkage and increased precision without any chance of manual errors during fabrication process could be attributed for this. Mean vertical marginal gap of the copings obtained using DMLS technique (G3) 10.52 μm shows comparatively least value than the other two groups. Cobalt chromium powdered alloy used in this technique has slight variations in composition. The molybdenum content in the alloy powder used in DMLS is comparatively less than the alloy which is used for conventional casting. Moreover this process have completely eliminated casting and manual errors and yielded good results, compared to induction coil casting procedure which was used to melt the alloy for group 1 and group 2 used in this study. This induction coil heating melts alloy at higher temperature than its melting range which causes the alloy to lose its low melting point compositional elements making it more viscous and affecting its flow. Another factor is the delayed time to melt alloy in an electrical machine, a condition that can also modify the alloys composition and consequent viscosity. Results of this study regarding vertical marginal gap of (10.52–45.36 μm) from all 30 copings were within the acceptable range and in consensus with those of Dedmon, WhiteSN, Mc Lean and, Hung, Swartz et al. [38].

The mean internal gap of 39.97 μm for copings obtained from inlay casting wax pattern (G1), 36.15 μm for copings obtained using 3D printed resin pattern (G2) and 41.27 μm for copings obtained using DMLS technique (G3, Graph 2).

The mean internal gap of the group 1 (G1) were 39.97 μm which was statistically more compared to the group 2 (G2), discrepancy between mold expansion and casting shrinkage could be the reason for this. The mean internal gap of (G2) copings 36.15 μm was statistically significant than (G1). Magix software which compensates for polymerization shrinkage and increased precision without any chance of manual errors during fabrication process can be attributed as a reason for this difference. Group 3 (G3) showed a mean internal gap of 41.27 μm. The same group had least marginal gap but the internal gap of these samples was statistically higher than the group 2 (G2) and group1 (G1) this could be because while scanning the master die and constructing three dimensional coping shell model image, the margin determination was done under manual adjustment while the external surface scanning of the master die was determined by the nonuniform offsetting and shelling algorithm in the scanning system software.

The CAD/CAM process of producing copings by DMLS technique using automated scanning process and powerful CAD software offers many advantages such as complete control over the framework and coping designing, margin placement, cement space maintenance, coping thickness and pontic designs as well as elimination of casting procedures. Also the composition of Co–Cr alloy used for laser sintering has lower molybdenum content compared to that Co–Cr alloy used for conventional casting. Presumably; Laser sintering of alloy is facilitated by the absence of such refractory metals which have higher melting range than cobalt and chromium. Further research would be of great use in these areas. Ucar Y et al. [3] did a study on internal fit evaluation of crowns fabricated using conventional casting technique and Laser sintered technology. Results from his study showed the mean internal gap widths of cast Co–Cr copings were 50.6 μm and that of Laser sintered technique was 62.6 μm which were in acceptance with the results obtained in this study. Results of internal gap of this study (36.15–41.27 μm) from all 30 copings were within the acceptable range and in consensus with those of Yurdanur Ucar, Bindl and Mormann.

The limitation in this study other than that this is a in vitro study which cannot simulate oral conditions was that the marginal gap were evaluated before sectioning of the casted copings and internal gap was evaluated after sectioning which could resulted in minimal fit discrepancy, but this was common for all test samples. The internal gap was measured 2 dimensionally, 3 dimensional evaluation of this gap would have yielded more accurate results regarding the space occupied by the luting agent. Also the horizontal gap was not evaluated.

Nevertheless several limitations mentioned above, this in vitro study suggested marginal fit of cast copings with three different fabrication techniques were within the range of clinically acceptable values as mentioned in the literatures.

Conclusion

In this in vitro study the copings obtained from DMLS technique show the least marginal gap when compared to cast copings obtained from inlay casting wax and 3D printed resin pattern and the internal fit was least for 3D printed resin pattern copings than copings from DMLS technique and inlay casting wax pattern which had results within clinically acceptable values. Conventional casting techniques and DMLS have yielded results within clinically acceptable range, but compared to conventional casting methods, the technique sensitive procedures are being completely eliminated in the DMLS technique. So further studies on this newly introduced 3D printed technology and DMLS technique should be carried out with various parameters to obtain confirmative and consistent estimate of the marginal and internal discrepancy with these techniques for their acceptance in dentistry.

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