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Research Article

Effect of repeated porcelain firing cycles on the marginal fit of cobalt chromium copings obtained by lost wax and DMLS techniques-an in-vitro comparative study

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Abstract

Background: Precise marginal adaptation influences longevity of restorations, limiting plaque accumulation and biomechanical complications. Thus study was undertaken to compare marginal fit of Co-Cr copings fabricated by direct metal laser sintering (DMLS) and conventional lost-wax casting at two production stages. **Materials and Methods:** An in-vitro study used a stainless-steel master die representing a prepared molar. Forty copings (n = 20 per technique) were produced, porcelain-veneered Vertical marginal gaps at four axial sites were measured with a digital stereomicroscope (100×, 0.1 μm accuracy) at coping, porcelain build-up. Data were analysed by one-way ANOVA with Tukey post-hoc tests (α = 0.05; power = 80 %). **Results:** Mean gaps (μm) for, DMLS and lost-wax respectively were: coping 20.91 ± 2.92, 65.82 ± 8.11; porcelain 22.86 ± 3.18, 74.52 ± 9.24; (P < 0.001). Gaps increased significantly through successive stages (P < 0.05) in DMLS (P > 0.05). All inter-group differences were statistically significant. All values remained below the 120 μm clinical threshold. **Conclusion:** DMLS provided the most accurate marginal fit. Lost-wax produced larger discrepancies yet remained clinically acceptable. Despite slight gap enlargement after porcelain firing and cementation, digital additive and subtractive workflows offer superior precision and efficiency for metal-ceramic crowns. Clinical validation is advised.

Keywords: marginal fit; DMLS; lost-wax; cobalt-chromium; metal-ceramic crown

Introduction:

Fixed prosthodontics is the branch of prosthodontics concerned with the replacement and/or restoration of the teeth by artificial substitutes that cannot be removed from the mouth by patient. Fixed dental prostheses range from the restoration of single tooth to whole mouth rehabilitation restoring function, patient comfort, masticatory ability, maintaining the health and integrity of the dental arches and in many instances elevates the patient's self-esteem by improving the esthetics. The pursuit of this success involves an intricate procedure called dental castings which has been an integral part of prosthodontics for more than a century. Precise marginal adaptation is necessary to achieve better mechanical, biological and esthetics prognosis of the restorations.¹ Generally marginal fit and internal fit of restorations are very much influenced by clinical and laboratory factors. Clinical factors are geometry of tooth preparation, including type of finish line and degree of taper, impression materials, and lastly cement used to lute the restoration in dental office.^{2,3} Laboratory factors that affect marginal gap and internal gap are incompatibility of dental materials such as wax, die stone and casting investment, die spacer and the casting technique.⁴ One of the new techniques for fabrication of alloy copings reported in the literature is Direct Metal Laser Sintering (DMLS) system. A typical fixed restoration, manufactured using a dental CAD system undergoes a

process of scanning and design, and CAM systems are divided into those using subtractive manufacturing (SM) and those using additive manufacturing (AM) methods.⁵ Additive manufacturing require a layer-by-layer free-form fabrication using various materials. DMLS is a CAD/CAM based technique in which frame works and metal copings can be designed and fabricated using cobalt chromium.⁶ Direct metal laser sintering (DMLS) is an additive metal fabrication technology uses a high temperature laser beam to selectively heat a substructure metal powder based on the CAD data with framework figure. Benefits of the DMLS system include easy fabrication of complex shapes, operation of an automatic system, and short working time due to removal of the procedures of fabricating a wax pattern, investing, burn out, and casting. The DMLS system could lessen metal waste by selectively shooting the required amount. One cons of the DMLS system is the cost of the equipment. While an important condition for a successful dental prosthesis is good marginal fit, there is a minute data on the marginal fit of fixed dental prostheses manufactured by the DMLS system.⁷ Thus, the present study was planned to compare and evaluate the marginal fit of (Co-Cr) copings fabricated by computer aided designing /computer aided milling technique, direct metal laser sintering technique and conventional lost wax technique at three production stages.

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Materials and Methods

This in vitro experimental study was conducted in the Department of Prosthodontics, Crown & Bridge. Sample size was determined using GPower 3.1.9.2 software with an effect size of 0.25, power of 80%, and a significance level of 5%,

resulting in a minimum requirement of 20 samples. A total of 40 samples were fabricated and divided into two groups (n=20 each):

Group A: Direct Metal Laser Sintering (DMLS)
Group B: Lost-Wax Technique

A customized stainless steel master die (fig.1) simulating a tooth preparation with a 6° taper, 6 mm axial height, and 1 mm shoulder finish line was fabricated. A "+" shaped groove on the occlusal surface served as an anti-rotational feature. This die was duplicated in Type IV die stone using a polyvinylsiloxane impression with a 1.5 mm spacer. The duplicated dies were screened for quality. Inclusion criterion was complete castings without visible flaws. Samples with bubbles, cracks, casting defects, incomplete milling/sintering, perforations, or porosities were excluded.

Group A (DMLS)

Duplicated dies were scanned (fig 2). The software-generated coping designs were transferred to a SISMA DMLS machine (Italy) and printed using Starbond Cos 30 Co-Cr alloy powder (Co 61.8–65.8%, Cr 23.7–25.7%, Mo 4.6–5.6%, W 4.9–5.9%, others). Layering was performed in 20 µm increments using a 200 W Yb-fibre laser. Finished sintered copings were cleaned, sandblasted, and seated. After milling, copings were cut, contoured, sandblasted, ultrasonically cleaned, and seated on the corresponding dies.

Group B (Lost-Wax Technique)

Standardized wax patterns were made on the duplicated stone dies using a stainless-steel former and inlay casting wax (fig 3). Each wax pattern was 0.5 mm thick and visually inspected under 3× magnification. Sprues were attached at 45 degree angle and the patterns were invested using phosphate-bonded investment in a ringless technique. Investment was vacuum-mixed and allowed to bench-set for 2–3 hours. Burnout was performed up to 950°C. Casting was done with Co-Cr alloy (Co 64.0%, Cr

28.5%, Mo 5.0%, Mn 1.0%) using an induction casting machine. Castings were sandblasted with 50 µm Al₂O₃ at 80 psi, inspected under 10× magnification, cleaned ultrasonically, and tried on their respective dies.

Porcelain Build-up

All copings from Groups A and B underwent identical ceramic veneering procedures. Each coping was oxidized in a ceramic furnace and underwent five firing cycles: oxidation, two opaque, dentin, and enamel firings. Finishing and polishing were done using appropriate burs to simulate a clinical scenario. (fig 4)

Marginal Fit Evaluation

Vertical marginal gaps were assessed at two stages:

1. Coping stage
2. After porcelain build-up

Each sample was placed on its corresponding die, and measurements were taken at four standard locations (0°, 90°, 180°, and 270°) using a digital stereomicroscope (Dewinter, 100× magnification, 0.1 µm accuracy). The groove on the occlusal surface ensured uniform seating. All observations were performed by a single operator blinded to group allocation. Statistical analysis was performed using Statistical Product and Service Solution (SPSS) version 16 for windows (SPSS Inc, Chicago, IL). Descriptive quantitative data was expressed as mean marginal discrepancy and standard deviation respectively. Intergroup comparison of means between two groups i.e., direct metal laser sintering (DMLS) System, lost-wax technique was done with the help of Unpaired t test. Confidence interval was set at 95% and probability of alpha error was set at 5%. Power of study was set at 80%.

Results

The marginal discrepancy values at each production stage—coping, porcelain build-up, were statistically analyzed and compared among the two groups: Group A (Direct Metal Laser Sintering or DMLS), and Group B (Lost-Wax technique).

At the coping stage, the mean marginal discrepancy was 20.91 ± 2.92 µm for Group A, and 65.82 ± 6.35 µm for Group B. Unpaired t test was used to find significance and suggested significant difference between both groups. At the porcelain build-up stage, mean marginal discrepancy increased slightly to 22.86 ± 2.21 µm (Group A), and 74.52 ± 4.61 µm (Group B). The differences remained highly significant among groups ($p < 0.001$).



Fig 1



Fig 2

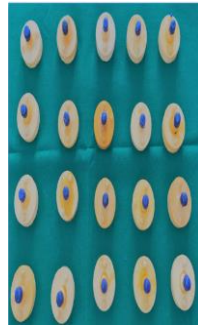


Fig 3



Table 1: Comparative statistics between Group A (DMLS) and Group B during coping stage

Coping	Group A (DMLS) Mean (SD)	Group B (Lost Wax technique) Mean (SD)	Unpaired t test	P value, Significance
0 Degree	20.65 (4.24)	62.25 (11.92)	t = -14.69	P<0.001**
90 Degree	21.15 (4.06)	66.7 (8.33)	t = -21.96	P<0.001**
180 Degree	20.3 (3.16)	68.7 (14.69)	t = -14.40	P<0.001**
270 Degree	21.55 (3.76)	65.65 (12.16)	t = -15.49	P<0.001**
Mean	20.91 (2.92)	65.82 (6.35)	t = -28.72	P<0.001**

**p<0.001 – highly significant difference

Table 2: Comparative statistics between Group A (DMLS) and Group B during build-up stage

Build-up	Group A (DMLS)	Group B (Lost Wax technique)	Unpaired t test	P value, Significance
0 Degree	21.95 (3.69)	64.6 (18.84)	t = -9.934	P<0.001**
90 Degree	23.3 (3.14)	70.3 (13.15)	t = -15.544	P<0.001**
180 Degree	23.75 (3.05)	82.15 (14.84)	t = -17.229	P<0.001**
270 Degree	25.65 (3.15)	82.3 (15.21)	t = -16.306	P<0.001**
Mean	22.86 (2.21)	74.52 (4.61)	t = -45.115	P<0.001**

**p<0.001 – highly significant difference

Discussion

The marginal fit of dental restorations is a crucial factor in determining the long-term clinical success of crowns. Numerous clinical failures have been linked to marginal discrepancies, with Schwartz et al.8 identifying defective margins as the cause in 11.3% of unserviceable crowns and bridges. While the conventional lost wax technique has been the standard for over a century, emerging technologies such as Direct Metal Laser Sintering (DMLS) offer the advantages of automation, reduced processing time, and potentially improved accuracy. The present study was designed to compare these two techniques—DMLS, and lost wax—by evaluating the marginal discrepancies of cobalt-chromium (Co-Cr) copings fabricated using each method at three clinically relevant stages: the coping stage, after porcelain build-up, and following cementation. A standardized stainless steel master model was fabricated in accordance with the design recommended by Gaikwad et al.9, featuring a 6° total axial wall taper, a 6 mm axial height, and a 1 mm shoulder finish line. This design aimed to simulate a prepared tooth and was consistent with previous research advocating shoulder or heavy chamfer preparations for optimal marginal fit. Forty Co-Cr copings were fabricated—twenty from each technique—and marginal discrepancies were measured at four standardized reference points using a stereo microscope at 100x magnification.

At the coping stage, the mean marginal discrepancy was found to be 20.91 µm for the DMLS group, and 65.82 µm for the lost wax group. The relatively high discrepancy in the lost wax group was likely due to dimensional changes in the inlay wax, including shrinkage and stress relaxation. The DMLS technique produced the lowest mean discrepancy, which can be attributed to its additive process that eliminates the casting and manual steps inherent in traditional methods.

These findings align with previously published results. McLean et al.10 reported post-casting marginal gaps in the range of 40 to 61.5 µm and

established a clinically acceptable limit of 120 µm. Hung et al. similarly suggested that marginal gaps within 50 to 75 µm are acceptable in clinical practice. The current study's findings for the CAD/CAM and DMLS techniques fall well below these thresholds. While the ADA recommends a marginal gap of 25 µm, this standard is rarely achieved in practice. Quante et al.11 noted that DMLS copings fabricated using laser sintering showed marginal gaps ranging from 76 to 93 µm, while Kim et al.12 reported values of 81.1 µm for DMLS, and 68.6 µm for lost wax. The results from the present study, particularly for the DMLS group, suggest improved accuracy due to technological advancements in laser sintering and digital design.

Following porcelain build-up, the mean marginal discrepancies increased slightly to 22.86 µm for DMLS, and 74.52 µm for lost wax. This increase in gap values is attributed to the distortion caused by the porcelain firing process. Zeng et al.13 documented marginal gap values of approximately 36 to 38 µm in SLM-fabricated copings after repeated porcelain firings. The DMLS group in this study demonstrated similar performance, suggesting the reliability of this method even after multiple firings. The five porcelain firing cycles used in this study reflect a typical clinical protocol, supporting the validity of the design.

Statistical analysis confirmed that the differences in marginal discrepancy among the two techniques remained highly significant after the porcelain build-up stage. While some studies, such as that by Kocaagaoglu et al.14, found no significant impact of porcelain firing on marginal fit, the present study clearly demonstrated an effect, especially in the lost wax group. Despite this, all marginal values remained within clinically acceptable limits. The increase in marginal discrepancy during porcelain build-up has been attributed to stress generated during the cooling phase of the firing cycle. Differences in thermal contraction between the metal coping and porcelain layer may create internal stresses that distort the restoration. Historical studies by Howell and others noted

changes in marginal fit after firing, with theories suggesting that porcelain shrinkage or metal-porcelain interfacial stress plays a role in distortion. More rigid restorations are generally less susceptible to this effect.

The majority of marginal discrepancy appears to develop during the oxidation cycle, which may release residual stresses accumulated during the casting, grinding, or polishing phases. Additional discrepancy may result from the difference in contraction rates between porcelain and metal as the restoration cools from the firing temperature. Anusavice et al.¹⁵ suggested that thermal incompatibility stresses could lead to distortion, although there is some debate about whether metal-porcelain incompatibility or other factors are primarily responsible. Buchanan et al.¹⁶ observed that base metal alloys tend to develop greater marginal discrepancies compared to noble metal alloys, possibly due to thicker oxide layers formed during firing.

Intragroup analysis revealed a statistically significant increase in marginal discrepancy across the three stages in all groups. The DMLS group also showed significant increases, particularly between the coping and cementation stages. The increase between build-up and cementation, however, was not statistically significant. The lost wax group showed a highly significant increase in marginal discrepancy at each stage, confirming that this technique is more prone to cumulative dimensional changes during processing.

The results of this study demonstrate that the DMLS technique consistently produced the lowest marginal discrepancies at all stages. The lost wax technique, while producing the highest discrepancies, still delivered results within clinically acceptable limits. The superior performance of the DMLS group may be due to the elimination of casting procedures, manual wax-up, and investment burnout, which are inherent in the lost wax technique. DMLS consolidates metal powders at a microscopic level, enhancing precision and marginal adaptation.

As for the two stages evaluated, there was a consistent trend of increasing marginal discrepancy from the coping stage to porcelain build-up and finally to cementation, regardless of the fabrication technique used. This trend highlights the cumulative effects of multiple processing steps on the fit of the final restoration.

Each technique has its advantages and drawbacks. The DMLS technique, although expensive, minimizes material waste, removes the need for manual intervention, and offers high precision. Its wider adoption is currently limited by setup costs. In contrast, the lost wax technique remains a cost-effective and time-tested method, suitable for practice in regions with limited technological access despite its technique sensitivity and labor demands.

Some limitations must be acknowledged. The Co-Cr alloy composition varied across the three fabrication techniques, which may have influenced the results. Only marginal fit was evaluated; including internal fit analysis could have provided a more comprehensive assessment. The 100x magnification used may have limited the detection of finer discrepancies; a scanning electron microscope (SEM) might yield more accurate results. Also, only the cementation stage was standardized using a constant load, while other stages relied on finger pressure, which may introduce variability. The sample size of 20 per group and the in vitro nature of the study also limit generalizability to clinical practice. Future research with larger sample sizes, higher-resolution imaging, and in vivo studies is recommended to validate these findings.

Within these limitations, it can be concluded that marginal discrepancies of metal-ceramic copings fabricated using DMLS, and lost wax techniques remain within clinically acceptable limits across all three production stages. Among the techniques, DMLS demonstrated the best marginal adaptation. Although the lost wax technique showed comparatively higher discrepancies, the results were still within the acceptable range. These findings support the potential for DMLS techniques to serve as viable, and in some cases superior, alternatives to conventional casting. Increased accessibility and reduced costs could further promote their adoption in routine prosthodontic practice.

Conclusion

Within the inherent limitations of this study, it can be inferred that the findings of this study can be used in clinical prosthetic dentistry in the following ways. Marginal discrepancy of metal ceramic copings at all the production stages, viz. coping stage, porcelain build up stage and post cementation stage were well within the clinically acceptable range of 120µm, hence either of the three can be used to obtain cast copings. Direct metal Laser sintering of Co-Cr alloy crowns seem to be the most promising technique, producing the lowest marginal discrepancy. With decreased in production cost and establishment of DMLS laboratories on a wider scale would make it the most preferred technique of obtaining cast copings. However, the repeated porcelain firings and cementation procedures do affect the fitting accuracy of metal-ceramic restorations fabricated with these technologies.

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