



Original Article

Evaluation of marginal adaptation of Co–Cr–Mo metal crowns fabricated by traditional method and computer-aided technologies



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KEYWORDS

Conventional lost wax and casting method;
Computer-aided design/computer-aided manufacturing;
Direct metal laser sintering;
Marginal adaptation

Abstract *Background/purpose:* The purpose of this study was to evaluate the marginal gaps of dental restorations manufactured using conventional lost wax and casting, computer-aided design/computer-aided manufacturing (CAD/CAM), and 3D printing methods.

Materials and methods: A zirconia master die model with an upper right first molar resin crown was prepared as a standardized model. A total of 30 resin master die models were duplicated from this standard model. Simultaneously, 10 Co–Cr–Mo metal crowns were individually obtained using the conventional lost wax and casting method (Group A), selective laser sintering (Group B), and CAD/CAM (Group C), respectively. The marginal gaps between the crowns fabricated conventional and digital methods with master die models were calculated using a 3D replica and mapping technique.

Results: Statistical analyses revealed there were significant differences in the marginal gaps in the group A with group B and C ($p < 0.05$). The mean marginal gaps between dental crowns with die models were $76 \pm 61 \mu\text{m}$, $116 \pm 92 \mu\text{m}$, and $121 \pm 98 \mu\text{m}$ for groups A, B, and C, respectively.

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Conclusion: Within the limitations of this study, the marginal gaps were clinical acceptable in conventional and digital techniques.

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Introduction

In prosthodontics, fabricating dental restorations using conventional techniques has been considered the gold standard technique for several decades. High-quality restorations can be achieved by experienced dental technicians in a series of precision conventional lost wax and casting manufacturing processes. Recently, more and more digital technologies, such as the dental computer-aided design and computer-aided manufacturing (CAD/CAM) system (subtractive manufacturing)^{1,2} or the surgical planning system,^{3,4} have been developed to assist clinicians to complete treatments effectively. In these digital systems, the dental CAD/CAM systems are generally used to improve the effectiveness of prosthesis fabrications. These new systems were also gradually developed as alternatives to the conventional lost wax and casting method to produce more effective and standardized dental prostheses. The feature of dental prosthesis using digital methods are high accuracy, detailed resolution, good surface quality, and excellent mechanical properties.⁵

In digital manufacturing procedures, dental restorations are commonly fabricated using the CAD/CAM system in a dental laboratory. By using dental model information from an intra/extra oral scanner, dental technicians can design corresponding prostheses in a digital environment according to the aesthetics and occlusal function. The finished restoration model is then exported into a stereolithography (STL) file format and fabricated using a dental CAM machine. Moreover, complicated materials, such as ceramic-metal materials, are commonly used in fixed dental prosthesis (FDP).⁵ Compared with manual production, the complicated materials in restorations can be more effectively employed through the CAD/CAM system. Other than the CAD/CAM system, 3D printing technology (additive manufacturing) is also popular in many clinical applications. Recently, 3D printing technologies, such as the selective laser sintering (SLS) system, has been applied to dental restoration fabrications. A key feature of the SLS system is that dental restorations can be fabricated layer by layer under a high-temperature laser beam to substantively structure a metal powder environment.⁶ Unlike the CAM system, 3D printing technology uses the additive manufacturing method. Advantages of 3D printing include reducing the amount of material used and obtaining high restoration accuracy during production. The 3D printing method is convenient for crown fabrication, especially for complicated profiles. Thus, the direct metal laser sintering method is a currently used technique for fabricating dental prostheses in clinical practice.

The precision of dental restorations is always emphasized in clinical treatment. A favorable adaptation between

a crown restoration and an abutment tooth not only ensures good mechanical behavior, but also prevents bacterial infiltration. Numerous requirements must be considered for the proper function and durability of a crown restoration in the oral cavity to achieve an ideal dental restoration. Studies have indicated that the major reason for dental restoration failure is inappropriate gaps.^{7,8} Thus, the gap between a crown restoration and an abutment tooth is a pertinent factor in dental prostheses.^{8–11} Marginal and internal gaps are mostly evaluated using 2D or 3D optical technologies to verify the adaptation of dental restorations.¹² Using optical technologies, clinicians can mathematically understand internal gaps in different phases of restoration and can adjust errors to obtain restorations in clinical settings. Although ideal restorations are commonly obtained using manual manufacturing processes in current dentistry treatments, dental restorations made using different digital systems have gradually become popular in prosthodontics.

Investigating the marginal gap between a crown restoration and an abutment tooth has always a pertinent concern in clinical practice. However, research on its clinical utility through comparing digital systems with conventional methods is still limited. The purpose of this study was to measure the marginal gaps of crown restorations using a 3D optical mapping technique to compare three types of cobalt-chromium-molybdenum (Co–Cr–Mo) metal crowns fabricated using the conventional lost wax and casting method, CAD/CAM method, and SLS method.

Materials and methods

In this study, a zirconia master die model with an upper right first molar resin crown was prepared as a standardized model. A total of 30 resin master die models, 10 for each test group, were duplicated according to the standard die model. Simultaneously, 10 Co–Cr–Mo metal crowns were individually obtained using the conventional lost wax and casting method (Group A), the SLS method (Group B), and the CAD/CAM method (Group C). The marginal gaps between dental crowns fabricated using these three methods with the die model were analyzed using a 3D replica and a mapping technique.

Preparing the standardized zirconia master die model and crown model

The zirconia die model with an upper right first molar was prepared in advance. The marginal part of the molar was prepared with a depth of 1.0 mm in a chamfer form, the occlusal table was evenly reduced to a thickness of 1.5 mm,

and an angle of the adjacent surface was designed at 6° to create the standard master die model. To ensure that the crown was correctly positioned on the master die, there were two wedge-shaped indexes designed over the central portion of the buccal and palatal margins. The standardized zirconia die model was transferred into a digital STL file using an IScan L1 dental scanner (IScan L1, Imetric 3D SA, Courgenay, Switzerland) (Fig. 1). The relative scanning file was then imported into a CAM machine to duplicate the resin models.

An experienced technician designed the corresponding crown of the standardized model using Exocad DentalCAD software (Fig. 2). In the design procedure, the cement thickness of the crown was set to $30\ \mu\text{m}$, starting from 0.5 mm behind the margin, as suggested by the manufacturer. The crown's thickness was according to the original thickness that was reduced when creating the standard zirconia master die model. The corresponding crown was transferred into an STL file and manufactured using the CAM machine for the standard crown model.

Fabricating the metal crown using the conventional loss wax and casting method

According to the standard crown model, a total of 10 casting metal crowns were fabricated with a Co–Cr–Mo alloy (Group A) in a dental laboratory. The laboratory procedures of casting the metal crowns were completed by the same technician, and were divided into three steps: (1) the standard zirconia die model was combined with the standard crown as a reference model. (2) A module was constructed on these references using vinyl polysiloxane silicone (VPS) impression materials. (3) A molten wax pattern was injected into the space of a silicone module. The reference model was then inserted into a wax-filled module. After the wax was cooled, the reference model was separated, and the wax pattern was removed from the silicone module. A total of 10 wax pattern duplications were manufactured using the VPS silicone impression materials. (4) All wax patterns were spruced, invested with phosphate-bonded investment material (Univest Non-Precious, Shofu Inc., Kyoto, Japan), and cast into a Co–Cr–Mo alloy (Co: 59.5%, Cr: 31.5%, Mo: 5%, Si: 2%, and Ce, Nb, Fe, N >1%) (BEGO Wirobond, Bremen, Germany). After divesting, the crown specimens were finished with mounted aluminum oxide stones ($75\ \mu\text{m}$ grit; Shofu Dental Corp., San

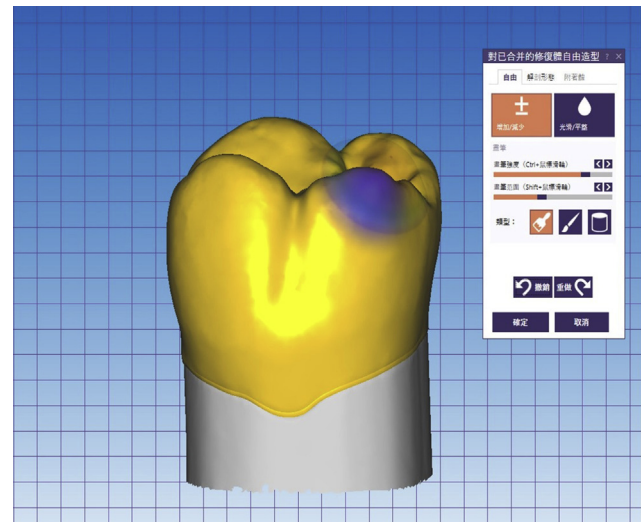


Figure 2 Corresponding crown designed using Exocad DentalCAD software and fitted with the zirconia die model.

Marcos, CA, USA) and airborne-particle abraded with $125\ \mu\text{m}$ of aluminous oxide particles (Cobra, Renfert, Hiltzingen, Germany) at 75 psi. (5) The airborne-particle abrading was standardized using a device that maintains patterns 5 cm from the tip of the airborne-particle abrading unit, and then the blasted surface was cleaned with steam.¹³ (6) After sandblasting, the crown specimens were inspected with an optical microscope at an original magnification of $10\times$ (Optiphot-pol; Nikon, Kanagawa, Japan), and then tested with the standard zirconia die model using a silicone-disclosing paste (Fit Checker; GC Corp., Tokyo, Japan). (7) When the crown specimens were completely set on the standard model, we waited to measure the marginal gap adaptation.

Fabricating the metal crowns using the SLS and CAD/CAM methods

From the STL file of a standard crown presented in Fig. 2, 10 Co–Cr–Mo alloy crowns (Group B) were fabricated using an EOSINT M270 with the SLS technique (EOS M270, Munich, Germany). The Co–Cr–Mo SP2 powder (Co: 63.9%, Cr: 24.7%, W: 5.4%, Mo: 5%, and Si \leq 1%) (BEGO Wirobond, Bremen, Germany) meets EN ISO 10993-5 standards for biological gaps

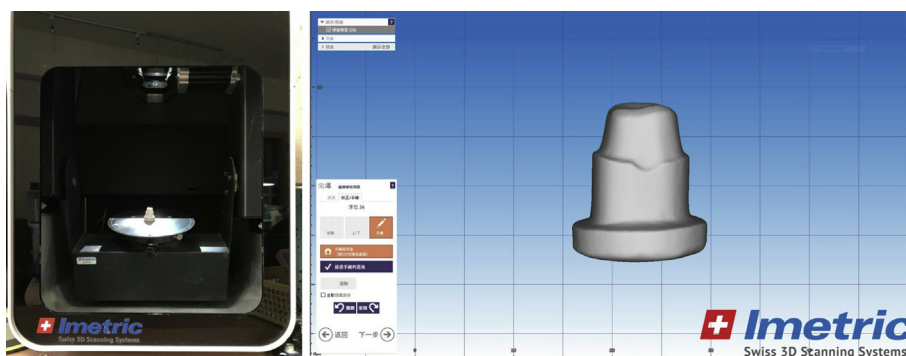


Figure 1 Zirconia die model scanned using an IScan L1 dental scanner to obtain a STL file.

as well as cell toxicity requirements. The same technician confirmed the appearance of all the crowns manufactured using the SLS method. To compare the margin gaps of different digital manufacturing techniques, 10 Co–Cr–Mo alloy crowns (Group C) were fabricated using the CAD/CAM system. The STL file of the standard crown model shown in Fig. 2 was imported into the CAM machine to manufacture the metal crowns. The same technician confirmed the appearance of the finished products.

Measuring marginal gaps using a 3D replica and mapping technique

To verify the marginal gaps, the inside of the crowns fabricated for groups A, B, and C were filled with light-body silicone (Take 1 Advanced; Kerr, Orange County, CA, USA). The crowns were pressured onto the duplicated resin models along the long axis with 50 N for 10 min until the light-body silicone hardened completely.¹⁴

The silicone-coated resin models were then secondarily scanned using an IScan L1 dental scanner and exported to the STL files (Fig. 3). To calculate the marginal gaps, the original standard and silicone-coated models were digitally mapped by accuracy analysis module of MIRDC Dental software (Metal Industry Research Development Centre, Kaohsiung, Taiwan).³ The superimposition of these two models was performed by aligning the corresponding matrix based on a number of planes (mesial, distal, buccal, and lingual) and mapped points. The deviation of the marginal part was then indicated by 230 points to calculate the marginal gaps (Fig. 4).

Data analysis

The marginal gap adaptation was calculated for the 10 specimens in each group. To confirm the marginal gaps,

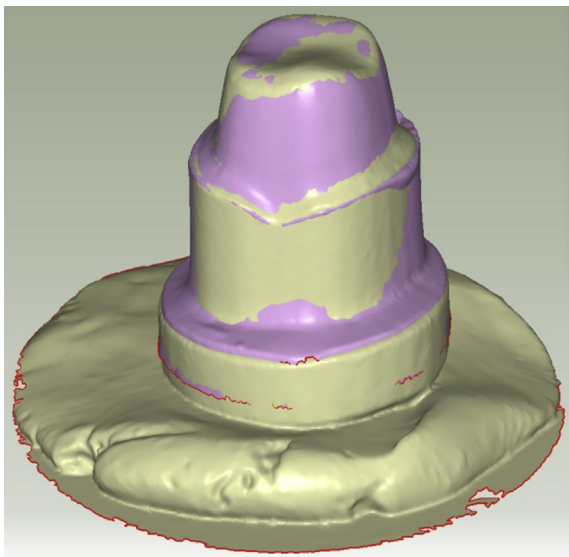


Figure 3 Superimposition of the original standard and silicone-filled models in MIRDC Dental software (original standard model: Pale Goldenrod color, silicone-filled model: purple color).

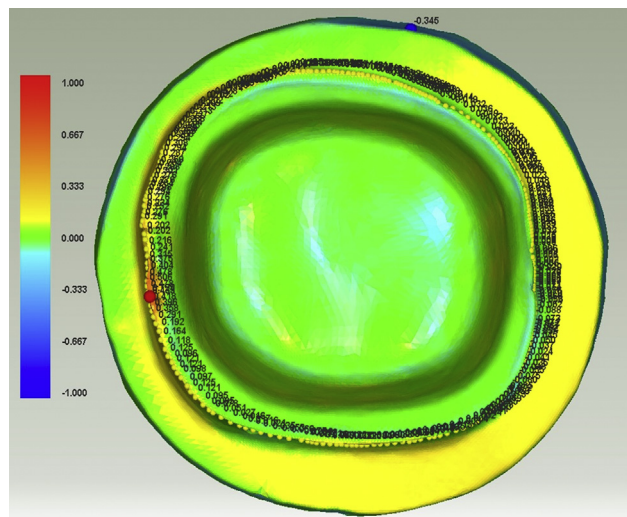


Figure 4 Deviation validation between the original standard and silicone-filled models (occlusal view).

four anatomy phases (mesial, distal, buccal, and lingual directions) were averaged and divided for evaluation. The results were analyzed using SPSS software (SPSS Inc., Chicago, IL, USA). Differences between groups A, B, and C were tested using a paired samples *t* test. A significant difference was observed when $p < 0.05$.

Results

The obtained deviations between original and standard and silicone-coated models were used to evaluate the variations of marginal gaps (Fig. 5). The mean marginal gaps were $76 \pm 61 \mu\text{m}$, $116 \pm 92 \mu\text{m}$, and $121 \pm 98 \mu\text{m}$ in groups A, B, and C, respectively. There were significant differences in the marginal gaps were observed in the group A with group B and C ($p < 0.05$). The marginal gaps in the four anatomical phases were calculated (Table 1). From the results, there were greater deviations in lingual phase in group A, B and C ($84 \pm 66 \mu\text{m}$ in group A, $120 \pm 103 \mu\text{m}$ in group B, and $178 \pm 120 \mu\text{m}$ in groups C).

Discussion

Marginal and internal gaps are usually evaluated in clinical practice to determine the fitness of crown restorations. When verifying the adaptation of dental crown prostheses using conventional methods, marginal and internal gaps are evaluated by applying crown restorations onto the abutments, cutting them, and observing their cross-sections under a microscope.¹² Although these gaps can be easily observed using a microscope, the disadvantage of this method is that it is 2D, making it difficult to measure gaps precisely from different directions in a cross-section specimen. Conversely, an optical 3D mapping technique is relatively accurate, stable, and enables 3D measurements from different directions.^{15,16} By using an optical mapping technique, marginal gaps can be calculated on a 3D surface, and this information enables clinicians to understand

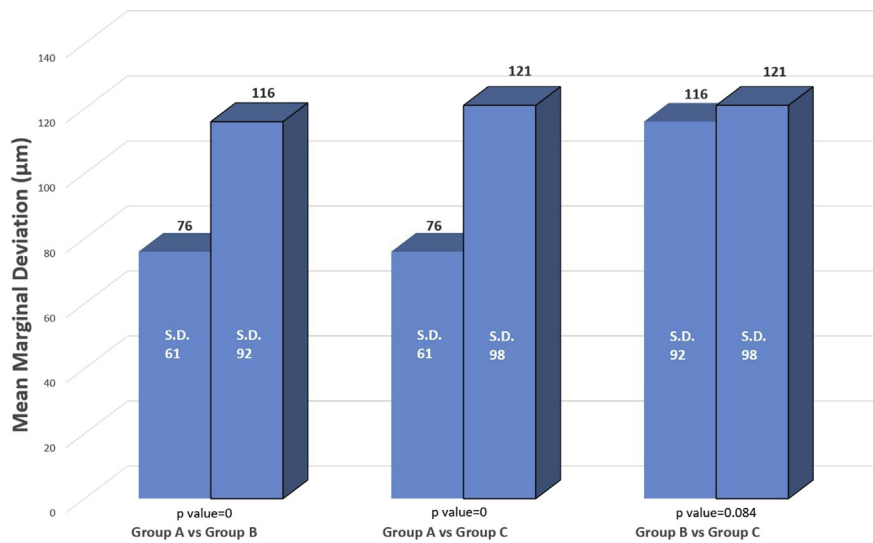


Figure 5 Deviation between the original standard and silicone-filled models (n = 2300).

the adaptation of restorations. Compared with conventional evaluation methods, optical mapping techniques are nondestructive and enable measurements in a natural setting without the need to cut the specimen. Furthermore, a 3D mapping analysis provides more than 20,000 measurement points per testing specimen, enabling the whole internal surface of a crown restoration to be analyzed, and offers a consistent reproduction of the internal texture without data loss due to cutting the specimen.¹⁷

Other than the information of marginal and internal gaps, marginal gaps have been individually calculated in some studies to evaluate the fitness of dental restorations.^{18,19} In clinical settings, large marginal gaps not only attach to the fitness of a restoration, but also easily cause secondary dental caries.²⁰ Thus, marginal gaps are considered a pertinent factor for evaluating the fitness of dental restorations in advance. In this study, the marginal gap region was selected using 230 points in each specimen, which was divided into four phases to evaluate the discrepancy values. The mean marginal gaps were $76 \pm 61 \mu\text{m}$, $116 \pm 92 \mu\text{m}$, and $121 \pm 98 \mu\text{m}$ in groups A, B, and C, respectively. The clinically permitted range for a restoration margin is still under investigation. In relative research studies,^{18,21–23} the clinically permitted range of a restoration margin was 45–200 μm . In this study, the

calculated marginal gaps in groups A, B, and C revealed that the discrepancy values were within this range. There was a better accuracy of marginal gap in group A and this result was also similar to recently study.²³ However, a higher discrepancy value occurred in the lingual direction in all three groups. The marginal gaps in the lingual phase were $84 \pm 66 \mu\text{m}$, $120 \pm 103 \mu\text{m}$, and $178 \pm 120 \mu\text{m}$ in groups A, B, and C, respectively. In this study, the 3D replica mapping technique was performed by an experienced technician to calculate the marginal gaps. To verify the accuracy of the marginal gap calculations, the crown, filled with light-body silicone, was manually pressured onto the resin models along the long axis until the silicone hardened completely. However, a manual error may have occurred during this process. In addition, the negative value of mapped data might be occurred in the marginal region due to the process of removing excess silicone from the prosthesis and model, and the internal gap was calculated by reselected point data in scanned model.¹⁴ In this study, in order to obtain the accuracy and complete marginal gap, removing excess light body silicone was precisely operated by an experienced technician and the negative value of deviations were very few by 3D mapping method. The negative deviation were then deserted for marginal gap calculation. Although the few of negative values were ignored, it had little effect on the overall result.

It is popular in clinical treatment for dental restorations to be manufactured using a digital system. However, some limitations still occur during manufacturing procedures. In the CAD/CAM system, the marginal and internal fit were not adequate, which resulted in wasted material during the milling procedures.²² Moreover, a sharp edge or undercutting in part of the dental restoration occurred easily when using the CAD/CAM system in the production procedure.²⁴ The reason for this might be that relatively large marginal gaps occurred due to the degree of freedom of milling kits in the CAD/CAM procedure. Compared with the CAD/CAM system, the 3D printing system avoided the unnecessary exhaustion of materials and provided more application in

Table 1 Marginal gaps in four anatomical phases (n = 575 in each phase).

	Group A	Group B*	Group C†
Mesial	$80 \pm 58 \mu\text{m}$	$119 \pm 76 \mu\text{m}$	$112 \pm 56 \mu\text{m}$
Distal	$78 \pm 65 \mu\text{m}$	$110 \pm 89 \mu\text{m}$	$103 \pm 95 \mu\text{m}$
Buccal	$63 \pm 51 \mu\text{m}$	$112 \pm 99 \mu\text{m}$	$89 \pm 83 \mu\text{m}$
Lingual	$84 \pm 66 \mu\text{m}$	$120 \pm 103 \mu\text{m}$	$178 \pm 120 \mu\text{m}$

Symbol * indicated there is significant difference in total mean of marginal gap in group A and B ($p < 0.05$).

Symbol † indicated there is significant difference in total mean of marginal gap in group A and C ($p < 0.05$).

the production process. Studies have indicated that some metal core distortions occur at high temperatures during the 3D printing manufacture process, resulting in marginal gaps in dental restorations.^{6,25–27} However, higher accuracy was achieved when using the 3D printing system compared with the CAD/CAM system for manufacturing the dental crown restorations. The 3D printing results in this study were consistent with those in related studies.^{22,23} By using these systems, dental restorations could be effectively obtained, which saved manufacturing time compared with the traditional manual method. In a digital environment, dental clinicians can visually design and evaluate the aesthetics of restorations in advance. However, some limitations in these digital systems still need to be overcome to obtain an ideal restoration.

The present study revealed that there were significant differences in group A with B and C group in terms of efficacy. The conventional casting method achieved a favorable fitness result than the CAD/CAM and 3D printing methods did. Generally, more time was required for the casting method compared with the other two methods when fabricating the restorations, but the accuracy and quality could be manually obtained using a series of conventional precision procedures. Although the CAD/CAM and 3D printing methods improve the effectiveness of dental restorations, the cost of these systems is still high for dental technicians. In addition, the restoration manufactured by these digital systems usually needed secondary adjustment by the dental technician. Thus, most dental restorations are still fabricated using the traditional casting method in dental clinical treatments. Although the CAD/CAM system was less accurate than the 3D printing system in this study, the quality of the dental restoration was not significant in clinical practice. This study had some limitations. The dental crown restoration using the conventional loss wax and casting method was performed by the same technician. More dental crowns fabricated using the conventional casting method by different technicians might be required to evaluate the accuracy of the marginal gap results presented here.

In conclusion, the marginal gaps of dental crown restorations fabricated using three methods were evaluated in this study. The conventional loss wax and casting method was better accuracy in marginal gap than the 3D printing and CAD/CAM system, but the traditional and digital techniques were all applicable to dental restoration application.

Conflicts of interest

None declared.

Acknowledgments

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