Dentistry 3000

Vol 14, No 1 (2026)
ISSN 2167-8677 (online)
DOI 10.5195/d3000/2026.1135

Marginal Fit of Metal Copings Made by Three Fabrication Routes

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Abstract

Objective: The accuracy of marginal fit is essential for the longevity of metal restorations because any gap increases biological and mechanical risks. Digital fabrication methods, such as milling and 3D printing, were introduced to reduce the errors seen in conventional casting. This study compares the marginal gaps of copings made by the three techniques to identify the most accurate method within clinical limits. **Materials and Methods:** Thirty copings, ten per technique, were made on a standardized maxillary molar preparation. Vertical marginal gaps were measured at the buccal and lingual reference points under a stereo microscope at ×40 using image analysis software. **Results:** Mean marginal gap was 36.05 μm for printed Co-Cr, 45.15 μm for milled Ti, and 67.04 μm for cast Co-Cr. Differences were significant at $p \leq 0.05$. **Conclusion**: 3D printing produced the smallest gaps, followed by milling, then casting. All means were within a commonly accepted clinical limit of 100 μm. Clinical significance, digital workflows can reduce inaccuracy and support restoration longevity.

Open Access

Citation: Al-Gebori SKR et al. (2026) Marginal Fit of Metal Copings Made by Three Fabrication Routes. Dentistry 3000. 1:a001 doi:10.5195/d3000.2026.1135
Received: January 4, 2026
Accepted: January 7, 2026
Published: February 17, 2026

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Introduction

Long-term clinical success of fixed dental prostheses (FDPs, is largely dependent on the precision of the restoration's fit, which is essential for achieving a clinically acceptable and biologically compatible outcome [1]. The marginal fit refers to the gap or distance between the finish line of the prepared tooth and the margin of the dental restoration. It is a critical determinant of both the longevity of the restoration and the preservation of the underlying tooth structure [2]. In the absence of a passive fit, the risk of biomechanical complications such as framework distortion, screw loosening, or ceramic veneer debonding may increase due to inadequate dissipation of functional stresses within the prosthetic assembly [3]. Taggart introduced the lost wax technique in the early 1900s, which made it possible to fabricate metal crowns and other fixed dental restorations. However, this fabrication process demands a high level of technical expertise and is heavily influenced by the dental technician's proficiency and experience. The wax pattern stage presents significant challenges due to the material's high coefficient of thermal expansion, susceptibility to temperature variations, inherent brittleness, and the potential release of internal stresses. These factors render the wax highly distortion-prone, which may ultimately lead to dimensional change and marginal discrepancies in the final dental [4].

In dentistry, computer-aided design and computer-aided manufacturing (CAD/CAM) technology was introduced as a comprehensive digital workflow aimed at enhancing the precision and efficiency of restorative fabrication. Two primary manufacturing approaches are employed within this system: the additive method, in which the restoration is constructed layer by layer through material deposition (as in 3D printing), and the subtractive method, in which the restoration is milled from a prefabricated block of material using computer-controlled machinery [5].
This technique enables the production of restorations and models with highly accurate and detailed morphologies. However, several

Vol 14, No 1 (2026) DOI 10.5195/d3000/2026.1135

limitations are associated with the subtractive manufacturing process. These include substantial material waste during milling, as well as accuracy constraints imposed by the diameter of the cutting burs. Additionally, the milling burs tend to wear rapidly—particularly when fabricating larger components such as full-arch frameworks or dental models—which can negatively affect precision and surface quality over time [6]. Therefore, to overcome the inherent limitations of the subtractive manufacturing process, 3D printing technologies have been introduced into the field of dental prosthetics. These additive, layer-by-layer fabrication methods have gained increasing popularity due to their capability to produce highly accurate and detailed restorations with minimal material waste. Furthermore, 3D printing is regarded as a rapid and cost-effective technique that enables the efficient and precise fabrication of dental models and prostheses while significantly reducing production time and resource [7]. A selective laser sintering, stereo lithography, and 3D printing are a few additive techniques utilized in dentistry. SLA is the oldest and most widely used printing method. It successively cures layers of liquid photopolymer resin using an ultraviolet (UV) scanning laser. Time savings and standardized output are two benefits of 3D printing methods. This method makes it possible to produce models with good wear resistance on a big scale [8].
This study compares the marginal fit produced by these three routes and evaluates whether results fall within accepted clinical limits.

Material and Methods

A total of thirty metal copings were fabricated and divided into three groups according to the manufacturing technique employed (as determined by the designated statistical software version). Group I consisted of ten titanium copings fabricated using CAD/CAM milling technology; Group II comprised ten cobalt–chromium (Co-Cr) copings produced by conventional casting; and Group III included ten Co-Cr copings fabricated using 3D printing technology. A standardized maxillary first molar (dentoform) tooth (Nissin Dental Products Inc., Tokyo, Japan) was utilized as the reference model for all sample preparations. The tooth was prepared with occlusal reduction and axial reduction of about 1.5 mm and finishing line of suitable thickness of 1.2 mm, with convergence angle 60 [9], as show in Figure 1.

Design of copy

A 3D Shape extraoral scanner was utilized to scan the master die and obtain a three-dimensional virtual model of the prepared tooth. The scanning process required approximately one minute to complete. Using the associated 3D Shape software, a virtual model was generated from the captured images, allowing for accurate identification and delineation of the preparation margin and finish line. Subsequently, an appropriate tooth morphology was selected from the digital tooth library within the software to match the anatomical characteristics of the prepared tooth.

Fabrication of Co-Cr Using Traditional Casting
The resin master tooth was first duplicated using a silicone impression material system (Aquasil Ultra LV, Aquasil Soft Putty, and Light Body; Dentsply Caulk, Milford, DE, USA). The light body material was carefully injected around the prepared tooth to capture fine surface details, and a sectional tray loaded with putty was used to obtain a single-stage impression. After the impression had set, die stone was poured to produce the working model. A silicone impression was taken and poured with type IV dental stone to produce the master die.
Wax patterns were made on the die with uniform thickness (0.5 mm) and adapted precisely at the margins. Each pattern was sprued, invested with phosphate-bonded cast using a centrifugal casting machine. After cooling, the coping was divested, sandblasted, finished, polished, and inspected for defects [1], as show in Figure 2.

Fabrication of CADCAM Metal Copy
Subtractive Group
Using 3D modeling software (Exocad GmbH, Darmstadt, Germany), the digital model of the maxillary molar was utilized to design the titanium copings. The CAD model was developed with standardized parameters, including an occlusal and axial reduction of approximately 1.5 mm, a finishing line thickness of 1.2 mm, and a convergence angle of 6°. The finalized design files were exported in STL format and processed using a Redon GTR milling machine (Redon Technology, Turkey) as shown in Figures 3 and 4 to fabricate ten titanium copings from prefabricated titanium blanks. Following milling, the copings were carefully separated from the disc using a straight fissure bur mounted on a straight handpiece, and the surfaces were finished to obtain a smooth, uniform texture as shown in Figure 5.
Fabrication of 3d Printer Copy Additive Group

Fabrication of 3d printer copy additive group ten laser-sintered Co-Cr copings were fabricated using the CAD-designed data (Exocad). The laser sintering machine (Pro X, 100DP, 3D system) as shown in Figure 6 works on a movable platform by sintering the incremental layer of the Co-Cr alloy with thickness of the powder layer was 20 µm . The machine laid down a film of Co-Cr alloy powder and process was continued layer by layer until the complete structure of coping was fabricated. After sintering, the copings were cooled down to room temperature, as show in Figure 7.

Measurement of Cervical Marginal Gap
Holmes et al. (1989) defined the cervical marginal gap as the perpendicular distance between the finish line of the prepared tooth and the margin of the crown. In this study, the vertical marginal discrepancy between the metal coping margin and the cervical preparation line of the working die was evaluated at both the lingual and labial aspects for Groups A, B, and C using a stereomicroscope at 40× magnification. High-resolution images were captured and subsequently analyzed with image analysis software (DinoCapture2.0; AnMo Electronics Corp., Taiwan) to determine the vertical misfit for each coping within the respective groups) as shown in Figure 8 [10].

Results

The collected data were analyzed using one-way analysis of variance (ANOVA) to evaluate the differences in mean marginal gap among the three groups, assuming a normal distribution of the variable .Result showed highly significant difference among three groups as shown in table (1)
The mean ± standard deviation (SD) of the marginal gap for metal copings fabricated by 3D printing (Co–Cr), CAD/CAM milling (Ti), and conventional casting (Co–Cr alloys) were 36.05 µm, 45.15 µm, 67.04 µm respectively, as presented in Table 1 . Statistical analysis demonstrated a highly significant difference in marginal fit among the three fabrication methods ($p \leq 0.05$), indicating that the manufacturing technique substantially influences the marginal accuracy of the copings.

Discussion

Internal fit and marginal accuracy play very important roles in determining the longevity and clinical performance of fixed dental restorations [11]. Modern methods of digital technologies have significantly improved the precision of fixed prostheses during the past decades. The phosphate-bonded, ringless

Vol 14, No 1 (2026) DOI 10.5195/d3000/2026.1135

investment materials have also shown to increase the dimensional accuracy of cast restorations, however, the traditional casting methods are still very sensitive to technique, as well as vulnerable to distortion at wax patterning, investing, and metal casting [12]. In the current study, the mean marginal gap for Co–Cr copings that were 3D-printed showed the smallest amount (36.05 µm), followed by CAD/CAM-milled copings, and the greatest marginal gap (67.04 µm) was observed for the conventional casting group. While all fabrication processes achieved improvements within the clinically acceptable value (<100 µm), in all cases the additive synthesis performance was the best marginal performance. Such findings are also in agreement with (2) who reported far smaller marginal gaps for 3D-printed resin patterns than for milled PMMA patterns (82.21 µm against 106.75 µm). The increase in marginal accuracy for the 3D-printed group is ascribed to a layer-by-layer fabrication process, which reduces manual interfacing and prevents the appearance of wax pattern distortion, and provides uniform thermal control for heat in the metal fusion process. The additive process also decreases tool wear and operator-related variation, allowing more consistent application of internal, and marginal materials. The CAD/CAM-milled copings were as yet the only ones to reach the intermediate accuracy as reported [13], suggesting that hard Co–Cr alloys may result in reduced marginal accuracy by milling with tool wear and bur diameter variation. The subtractive nature of the procedure may introduce the micro error as well, especially at sharp angles or internal corners which cannot be easily duplicated with cutting tools. In contrast, the conventional casting group had the highest marginal gap in agreement with Shah et al. (2020), who also reported greater marginal gaps for cast Co–Cr copings with more milled-made objects [14]. The numerous manual steps in casting - including wax patterning, investing, and metal casting contribute to the accumulation of errors. Clinically, marginal gaps of less than 100 µm are also considered to be acceptable in terms of ADA Specification No. 8, while 50–75 µm is regarded as optimal (Hung et al., 1990). In this work, all manufacturing processes were acceptable, though additive manufacturing produced the better results. These results are thus consistent with the statement that 3D printing is a viable alternative to not only conventional casting but also milling based Co–Cr frameworks for producing accurate results.

Conclusion

In the confines of our in vitro work, fabrication method greatly influenced the marginal accuracy of cobalt-chromium copings in this report. The 3D-printed group produced the narrowest marginal gaps, followed by CAD/CAM machined copings, and the standard cast group appeared to have the largest discrepancies in terms of fabrication. Despite high contamination, all values fell within a clinically acceptable (<100 µm) range, but the precision obtained in additive manufacturing from a controlled additive manufacturing has already been significantly improved, due to the additive fabrication process based on an individual layer-by-layer basis, which minimizes mechanical deformation and manual error. It seems that 3D printing is a practical option as an alternate approach to achieve very accurate metal restoration materials, as compared to traditional and subtractive method.

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Vol 14, No 1 (2026) DOI 10.5195/d3000/2026.1135


Figure 1. Standardized maxillary first molar (dentoform) tooth.


Figure 2. Metal copy fabricated by traditional casting method.

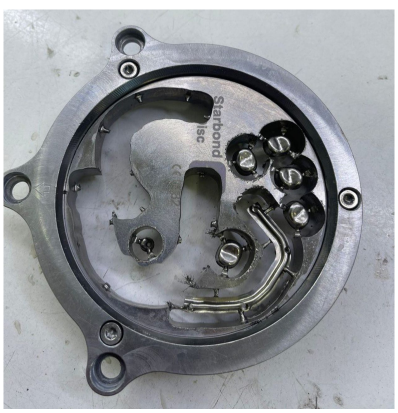
Figure 3. Titanium disc after CAD/CAM milling showing the frameworks still attached to the sprues after completion milling process.

Vol 14, No 1 (2026) DOI 10.5195/d3000/2026.1135

Figure 4. Cad cam machine used in this study.


Figure 5. Titanium metal copy fabricated by CAD/CAM.

Figure 6. 3Dprinter machine used in this study.


Figure 7. Metal copy fabricated by 3D printing.

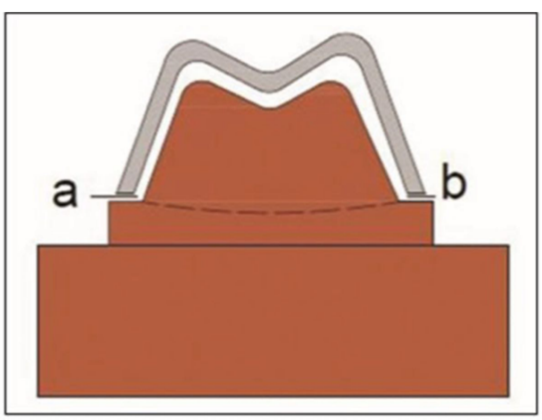

Figure 8. Measurement positions for assessing marginal gap (a and b) [10].