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Marginal Fit of Metal Copings Fabricated by Selective Laser Melting: An In Vitro Study

Abdullah Al-Mekhlafi [1] *, Mohsen Al-Hamzi[1, 2], Mohammad Al-Baili[1] and Ibrahim Kamel[1]

[1]**Department of Conservative Dentistry, Faculty of Dentistry, Sana'a University, Sana'a, Yemen,**
[2]**Department of Conservative Dentistry, Faculty of Dentistry, Dhamar University, Dhamar, Yemen.**

*Corresponding author: E-mail: abdalla.almklafi@su.edu.ye

Abstract

Introduction: Marginal adaptation is a key determinant of the clinical success and longevity of fixed dental restorations. Poor marginal fit is associated with microleakage, secondary caries, and periodontal disease. Selective laser melting (SLM), an additive manufacturing technique (AM), has been introduced as an alternative for fabricating metal restorations, offering high precision and reduced fabrication errors compared with conventional casting techniques.
Objective: This in vitro study evaluated the vertical marginal gap (VMG) of metal copings fabricated using SLM with two finish line thicknesses.
Materials and Methods: A sound human mandibular first molar was prepared for a porcelain-fused-to-metal crown with standardized dimensions. Two finish line configurations were created: a 1.0 mm round shoulder on the buccal surface and a 0.7 mm round shoulder on the lingual surface. The prepared tooth was digitally scanned, and 20 standardized resin dies were fabricated using a three-dimensional (3D) printing system. Twenty metal copings were designed using computer-aided design and manufacturing (CAD/CAM) software and fabricated using SLM under identical manufacturing parameters. The specimens were then cemented and sectioned in the buccolingual direction using a standardized guide. VMG was measured at predefined marginal points under a stereomicroscope at high magnification, and the digital images were analyzed using specialized software. Data were statistically analyzed using the Mann–Whitney U test, with significance set at $p \leq 0.05$.
Results: The SLM metal copings showed a total median marginal gap of 24.53 μm (IQR: 10.97–37.68 μm) with total median marginal gap in buccal margins of 20.82 μm (IQR: 9.96–29.18 μm), whereas the lingual margins showed a total median of 29.13 μm (IQR: 19.07–48.60 μm). Additionally, the marginal fit varied significantly between the buccal and lingual surfaces ($p < 0.001$).
Conclusion: The SLM technique showed there is a marginal gap, though it demonstrated a high marginal accuracy, that remained within clinically acceptable limits. Finish line thickness significantly affected marginal fitness.

Article Info

Keywords:
Selective Laser Melting, Additive manufacturing, Vertical Marginal Gap, Three Dimensional, Computer-Aided Design and Manufacturing, Subtractive manufacturing, Cross Sectional Method.

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1. INTRODUCTION

The marginal adaptation of fixed dental restorations plays a critical role in the clinical success of maintaining the integrity of the tooth-restoration interface [1]. Inadequate marginal fit has been consistently associated with microleakage, plaque accumulation, bacterial colonization, secondary caries, and periodontal disease, ultimately compromising the longevity of the restoration [2].

Marginal fit is defined as the linear discrepancy between the preparation finish line and restoration margin [3]. Clinically, marginal discrepancies are considered acceptable when they are visually undetectable or cannot be detected using a dental explorer. Values ranging from 100 to 150 μm are commonly cited as acceptable thresholds [4].

The lost-wax casting technique is considered a conventional method that demonstrates reliable long-term clinical outcomes in fixed prosthodontics [5]. However, this technique is highly sensitive. Wax patterns are fragile and prone to distortion during handling, which may negatively affect the accuracy of the final restoration [6]. Furthermore, casting procedures involving base metal alloys present additional technical challenges that may influence the consistency and reproducibility of marginal adaptation [7].

To overcome these limitations, digital technologies have been increasingly integrated into dental practice using computer-aided design and computer-aided manufacturing (CAD/CAM) systems. These systems include both subtractive (SM) and additive (AM) manufacturing approaches, offering improved standardization and reduced operator dependency [8]. Among AM techniques, selective laser melting (SLM) has emerged as a promising method for fabricating metal restorations, enabling the production of dense and homogeneous structures through a layer-by-layer laser fusion process [8]. Previous studies have reported that SLM can enhance manufacturing precision, reduce material waste, minimize human error, and eliminate several casting-related defects [9].

Previous studies have reported significant differences in marginal and internal fit among fabrication techniques, with milled restorations demonstrating superior marginal accuracy compared to both cast and SLM restorations, while SLM restorations showed the poorest internal fit and, in some cases, failed to achieve clinically acceptable values [10].

Recent studies have also reported significant differences in marginal adaptation between fabrication techniques, with conventionally cast restorations demonstrating superior marginal accuracy compared with CAD/CAM and selective laser sintering methods. The reported mean marginal gaps were approximately 76 μm for conventional casting, 116 m for SLM, and 121 μm for CAD/CAM restorations, although all values remained within clinically acceptable limits [11].

In contrast, other studies have demonstrated that digitally fabricated restorations exhibit significantly improved marginal fit compared to conventional techniques, with reported marginal gaps as low as 48 μm compared to 74 μm for conventional methods [12].

Despite the advantages of the SLM method, the marginal accuracy of SLM-fabricated metal coping remains a subject of ongoing investigation. Previous studies evaluating marginal fit have primarily focused on conventional casting techniques, with reported variability influenced by factors such as material properties, fabrication procedures, and clinical conditions [2]. However, the consistency of the reported outcomes remains unclear.

The purpose of this in vitro study was to evaluate the vertical marginal gap (VMG) of metal copings fabricated using (SLM), providing evidence to support clinical decision-making and improve restorative outcomes.

2. MATERIALS AND METHODS

2.1. Study design

This experimental in vitro study was conducted to evaluate the (VMG) of metal copings fabricated using (SLM) with two different finish line thicknesses, utilizing a cross-sectional evaluation method (CSM) approach. In this study, specimen fabrication was carried out in the laboratory facilities, while all subsequent examinations and measurements were conducted in the investigator's private office.

2.2. Sample Description

A single mandibular first molar with specific criteria was required to serve as a prototype. The criteria included a sound human mandibular first molar free of caries restorations, cracks, or structural defects. Teeth extracted for periodontal reasons were suitable. The samples were extracted, cleaned of debris, and stored in distilled water at room temperature.

Tooth preparation: The tooth was prepared by the researcher to receive a porcelain-fused-to-metal crown with standardized dimensions (1.5 mm occlusal reduction of 1.0 mm axial reduction, and convergence angle of approximately 10°–6°). Two different finish line thicknesses were prepared: a 1.0 mm round shoulder on the buccal surface and a 0.7 mm round shoulder on the lingual surface. A smooth, gradual transition between the two finish lines was created on the proximal surface. Standardization of tooth preparation was ensured using calibrated diamond burs and consistent preparation protocols.

Fabrication of resin dies: The prepared tooth was digitally scanned by a technician using a laboratory scanner (T-710, Medit Co., Republic of Korea), and a standardized digital model was generated with a base dimension of (1 × 1 × 0.5 cm) and labeled at the sides as (B, L, M, and D) (Figure 1). Twenty master resin dies were fabricated using a 3D printer (Anycubic Photon Mono 2 K) (Figure 2) with a 3D printing resin (ELEGOO UV-curing resin), post-cured, inspected for possible distortions, and numbered systematically.

2.3. Coping Design, Fabrication, and Cementation

Different coping designs were created for each die (one by one), and the sample number was engraved on the inner surface of the coping design using CAD software (Exocad Galway 3.0) (Figure 3), with the sample identifi-

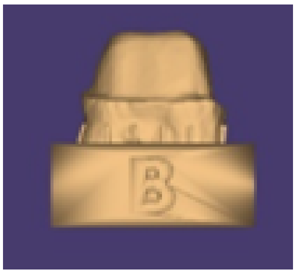

Figure 1. 3D Scan after editing

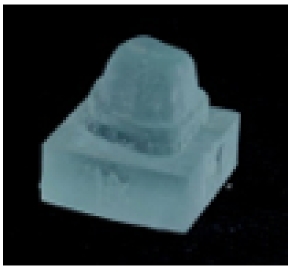

Figure 2. 3D resin printed die

cation engraved on the intaglio surface (Figure 4). The internal cement space parameter for all SLM metal copings was set to 80 µm.

The fabrication was performed using an SLM machine (FS121M-E, FARSOON Co., China) under manufacturer-recommended and standardized operating parameters. A cobalt–chromium alloy powder specifically designed for dental applications (Starbond Easy Powder 30, Scheftner, Germany) was used as the build material. The fabrication process was carried out with a laser spot diameter of 0.09 mm and layer thickness of 0.025 mm for each build cycle. All specimens were fabricated under identical conditions to ensure their consistency. Following fabrication and post-processing, all copings were carefully inspected for defects, and no defects were observed in any of the specimens.

Cementation was performed using a glass ionomer luting cement (Riva Luting, SDI, Australia). A standardized amount of cement was applied to each coping, which was then seated using finger pressure, followed by a controlled static load of 3 kg applied using an F-clamp

Figure 3. Designed coping in exocad

Figure 4. Copings numbering

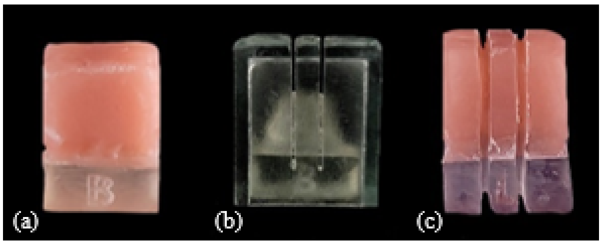

Figure 5. (a) Sample embedded in acrylic resin, (b) Sectioning guide, (c) Sample guiding groove.

for 5 min; excess cement was removed after setting. All cementation procedures were performed by the same researcher to ensure consistency.

2.4. Sectioning and Measurement

The specimens were embedded in auto-polymerizing acrylic resin to provide stability during sectioning (Figure 5. a). Each specimen was sectioned longitudinally in the buccolingual direction using a low-speed micromotor and diamond disc with a custom 3D-printed sectioning guide (Figure 5. b), which ensured accurate alignment and consistent sectioning (Figure 5. c).

Each specimen was divided into mesial, middle, and distal sections for analysis. Measurements were performed at eight predetermined marginal points: four buccal and four lingual points. The same reference points and measurement sequence were used for all specimens to ensure standardization.
Marginal discrepancy was measured according to the concept described by Holmes et al. [13], corresponding to the VMG, using a stereomicroscope (WILD M3) at 40× magnification with a 10× digital camera, achieving a total magnification of 400×. Digital images were analyzed using ImageView software (ImageView, Version x64) (Figure. 6).

System calibration was verified after each sample to ensure measurement accuracy and consistency of the results. To assess the measurement reliability, a subset of specimens was independently evaluated by a second examiner. Inter-examiner agreement was assessed, and the measurements were consistent.

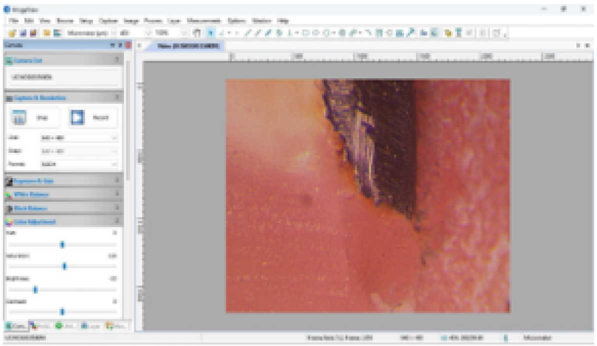

Figure 6. An image of the software associated with the digital camera for measurement.

Table 1. Descriptive statistics – Median and IQR of Metal copings marginal fit

SLM Metal Copings	N	Median	Percentiles		
			25	50	75
Buccal Margins	80	20.82	9.96	20.82	29.18
Lingual Margins	80	29.13	19.07	29.13	48.60
Total	160	24.53	10.97	24.53	37.68

2.5. Statistical Analysis

Statistical analyses were performed using SPSS software (version 29.0.1.0; Chicago, IL, USA). Data are expressed as median and interquartile range (IQR) due to non-normal distribution. The Mann–Whitney U test was used to compare the marginal discrepancies between the two finish line thicknesses, with statistical significance set at $p \leq 0.05$.

3. RESULTS

A total of 20 SLM-fabricated metal copings were evaluated, yielding 160 marginal measurements across the buccal and lingual surfaces. The overall median marginal gap was 24.53 µm (IQR: 10.97–37.68 µm). The buccal margins demonstrated a lower median marginal gap of 20.82 µm (IQR: 9.96–29.18 µm), whereas the lingual margins exhibited a higher median of 29.13 µm (IQR: 19.07–48.60 µm) (Table 1).

Statistical analysis revealed a significant difference in marginal fit between the two finish line thicknesses ($p < 0.001$) (Table 2), with a thicker buccal finish line demonstrating superior marginal adaptation (20.82 µm vs. 29.13 µm) (Table 1).

Table 2. Test Statistics – Mann-Whitney U test for marginal fit of buccal and lingual margins

	SLM Metal Copings (B, L)
Mann-Whitney U	2091.500
Z	-3.784
Asymp. Sig. (2-tailed)	<.001

4. DISCUSSION

This study evaluated the marginal fit of SLM-fabricated metal copings using a cross-sectional approach. The findings demonstrated a median marginal gap of 24.53 µm, which falls well within the clinically acceptable limits, confirming the high accuracy of SLM technology. In addition, all measured values were within the clinically acceptable thresholds (<120–150 µm), as previously reported in the literature [4, 14].

The selection of vertical marginal discrepancy as the evaluated outcome was based on its clinical significance, as it represents one of the most critical discrepancies affecting restoration longevity and cannot be easily corrected intraorally [13, 15].

These findings are consistent with those of previous studies reporting that digitally fabricated restorations can achieve clinically acceptable marginal fit values [12]. The improved accuracy associated with digital techniques may be attributed to reduced human intervention and elimination of errors associated with conventional wax and casting procedures [10, 16, 17].

However, the variability reported in the literature regarding the marginal accuracy of SLM-fabricated restorations helps to contextualize the present findings. While some studies have reported that milled restorations achieve better marginal and internal fit than both cast and SLM-fabricated restorations, with SLM occasionally showing higher marginal discrepancies and inconsistent performance [10], the current results demonstrate that SLM can still achieve clinically acceptable precision when appropriate parameters and standardized protocols are applied.

Similarly, although certain investigations have shown that digital workflows can improve marginal adaptation compared to conventional casting, with reported marginal gaps of approximately 48 µm versus 74 µm respectively [12], other studies have indicated that conventional casting may still demonstrate superior performance compared with both SLM and CAD/CAM approaches in terms of marginal accuracy, with mean values around 76 µm [11]. These differences suggest that no single fabrication technique consistently demonstrates superiority across all conditions.

In this context, the marginal gap observed in the present study (24.53 µm) supports the view that the accuracy of SLM restorations may be significantly influenced by factors such as scanning resolution, layer thickness, laser parameters, and postprocessing protocols. These variables likely contribute to the discrepancies reported across different studies and may explain the variations in the marginal fit outcomes in the literature.

The results of the present study also demonstrated that the finish line thickness significantly affects marginal adaptation, with thicker finish lines providing better seating and reduced marginal discrepancies. This finding is consistent with previous studies, indicating that the finish line design plays a critical role in marginal adaptation owing to its influence on cement escape, seating dynamics, and internal fit [18–20].

It is also important to consider the effect of cementation on the marginal fit. Previous studies have reported that marginal discrepancies increase after cementation owing to hydraulic pressure and incomplete seating, which may compromise restoration adaptation [21, 22]. Cementation techniques, including uncontrolled finger pressure or overfilling, can unevenly distribute cement and affect marginal fitness [23]. Therefore, the standardization of cementation in the present study likely contributed to the consistency of the results.

5. LIMITATIONS

This study had several limitations. First, the in vitro design does not fully replicate intraoral conditions, including saliva, occlusal forces, and thermal changes [24]. Second, although the sample size was consistent with previous in vitro studies, it may have affected the generalizability of the findings.

6. CONCLUSION

Within the limitations of this in vitro study, SLM-fabricated metal copings demonstrated high marginal accuracy, with all measured values within clinically acceptable limits. The results showed that an increased finish line thickness was associated with significantly improved marginal fit. Nevertheless, both the thick and thin finish line designs in this study exhibited marginal discrepancies within clinically acceptable limits.

These findings suggest that selective laser melting is a reliable fabrication method for producing metal copings with clinically acceptable marginal adaptation. However, given the variability reported in the literature, further comparative studies evaluating SLM against conventional and subtractive manufacturing techniques are recommended to establish its definitive clinical superiority.

Conflict of interest

The authors declare no conflicts of interest.

Ethical committee

The study protocol was approved by the Research Ethics Committee of the College of Dentistry, Sana'a University, Sana'a, Yemen.

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