Original Article

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Marginal Fit of Selective Laser Melting Cobalt-Chromium Bar Versus Cast Bar on Mandibular Edentulous Casts with Two Implants Supported Over Denture: An In vitro Study

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Abstract:

Objectives: This study aimed to evaluate and compare the fit of Cobalt Chromium customized bar fabricated with different manufacturing processes cast metal bar, and SLM metal bar utilizingUSB-digital microscope. **Methodology:**A physical mandibular edentulous cast was digitized and imported into Blender Dental for virtual model creation. Digital implant planning involved placement of two parallel bone-level implants with a 14 mm inter-implant distance. The virtual model was 3D printed, and the printed model was embedded with two implant analogs. Scan abutments were attached, scanned, and imported into Exocad for bar design. Twelve bars were fabricated: six using Selective Laser Melting (SLM) with Co-Cr alloy (Group I) and six using a combined digital-analog method (Group II). A USB digital microscope was used to evaluate the marginal fit at the implant-abutment interface. Using the Shapiro-Wilk and Kolmogorov-Smirnov tests, the data's normality was assessed. **Results:** Paired t-tests demonstrated significantly higher marginal fit values for casted frameworks compared to 3D-printed counterparts on buccal (56.05±7.65 µm vs. 34.19±6.03 µm, p=0.003) and overall surfaces (50.0±2.62 µm vs. 39.93±4.71 µm, p=0.002). While a trend towards higher fit was observed for cast frameworks on the proximal surface (54.39±8.25 µm vs. 45.17±7.62 µm, p=0.08), it did not reach statistical significance. Repeated Measures ANOVA revealed significant surface-related variations in marginal fit within both groups. In the cast group, the lingual surface exhibited the poorest fit (39.55±4.94 µm), while in the SLM group, the buccal surface demonstrated the least favorable fit (34.19±6.03 µm). **Conclusions:** This study demonstrated that both SLM and casted Co-Cr bars exhibited clinically acceptable marginal fit. However, SLM-fabricated bars demonstrated superior marginal fit at the implant-abutment interface in comparison to cast bars. These findings highlight the potential advantages of SLM technology in achieving high-precision and customized bar designs.

Keywords: Cobalt Chromium, dental Implant,3D printing, SLM, bar, casting, Internal fit

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Introduction:

One of the significant challenges for screw-retained implant prostheses is ensuring a passive fit of the prosthesis' superstructure to the implants. This passive fit is crucial for maintaining osseointegration. Passive fit of a dental restoration is achieved when the implant and prosthetic components exhibit optimal three-dimensional contact without inducing any strain or stress upon final screw tightening.[1], [2]

Both the biological and mechanical performance of the implant-supported prosthesis can be strongly impacted by the fit and microgap between the implant and customized bars. Microbial colonization within the implant-tissue interface can trigger peri-implant inflammation and bone resorption. This inflammatory response can induce bone strain and subsequent pain, ultimately leading to marginal bone loss and potential implant failure. [3], [4]Misfit between implant components may become more likely as the number, angulation, and distance between implants increase. Additionally, this problem may be made worse by the conventional final restoration workflow, which uses stone casts, impression materials, and analogs.[5]

For a variety of prosthetic restorations, implant abutments are either commercially available prefabricated (stock) components or can be customized to a patient's specific requirements.[6]Conventional casting methods, like the UCLA-type abutment fabrication method, can be used to customize bars and abutments. Castable UCLA abutments are typically fabricated in conjunction with a prefabricated cobalt-chromium base. This base, precisely designed to fit the implant's internal connection, minimizes the risk of distortion and misfit that can occur during the casting process.[7]To minimize internal misfit between implants and custom-made abutments and bars within a fully digital workflow, the Ti-Base abutment system has emerged as a viable solution. This system utilizes industrially prefabricated abutments that are compatible with both monolithic and bilayer superstructures, as well as various metallic bar designs, offering enhanced flexibility and compatibility within a digital workflow.[8], [9]

An important location for the concentration and transfer of occlusal forces to the implant is the abutment-implant interface. Consequently, minimizing clinical complications requires long-term firmness.

Inadequate implant-abutment interface fit can lead to prosthetic complications, including issues with the meso-structure and superstructure of the restoration. Micro-movement (micro-pumping), peri-implantitis, occlusal overload, loss of prosthesis passivity, abutment screw fractures, frequent screw loosening, wear and deformation of the implant interface, and loss of implant osseointegration are all possible side effects. [10], [11]

Cobalt-Chromium (Co-Cr) alloys have been extensively utilized in various dental applications owing to their favorable properties such as high strength, cost-effectiveness, and excellent corrosion resistance. However, the existing body of scientific literature on the application of Co-Cr alloys for implant restorations remains relatively limited.[12], [13]

Various methodologies have been described in the literature for assessing implant-abutment fit. Clinical evaluation typically involves visual inspection, radiographic assessment, and tactile evaluation using finger pressure to assess the joint interface. The Sheffield test and screw resistance test are considered highly sensitive for detecting any lack of passivity or implant-abutment misfit. Microscopic evaluation techniques, such as light microscopy and scanning electron microscopy (SEM), were employed to assess the microgap fit between the implant and abutment. Micro-gap fit can be evaluated using various methods, including finite element modeling, strain measurement, photoelastic stress analysis, and digital scan superimposition of the final framework on the master cast.[14], [15]

In recent years, computer-aided design and manufacturing (CAD/CAM) technology has facilitated the extensive use of custom-designed bars and abutments. This advancement offers several benefits, including reduced fabrication time, enhanced precision in customization, and a broad range of material options for manufacturing. CAD/CAM technology has emerged as a significant advancement over conventional casting techniques in dental restoration fabrication. This technology enables the precise machining of prefabricated blocks of various materials, including acrylic resins, composites, ceramics, cobalt-chromium alloys, and titanium alloys, offering enhanced precision and control over the final restoration. [16]

Research efforts and industrial applications are increasingly focused on evaluating the potential of additive manufacturing technologies to replace or supplement existing manufacturing systems. [17]These technologies are being employed for customized subperiosteal and endosseous titanium implants fabrication[18], [19], production of meshesfor various bone grafting procedures[20], [21], and production of fixed and removable implant-supported prostheses frameworks made of Co-Cr and Titanium.[22], [23], [24]

Therefore, the purpose of this in vitro investigation was to evaluate the marginal fit of Co-Cr customized bars made with various manufacturing processes. According to the null hypothesis, there are no significant differences in the marginal fit of Co-Cr customized bars made using casting and digital processes.

Sample Size Calculation

The sample size was calculated using an alpha (α) level of 5% and a beta (β) level of 10%, corresponding to a statistical power of 90%. Based on the findings of the study conducted by **Nassar and Fateen (2023)**[25], the minimum required sample size was determined to be six subjects per group, resulting in a total of 12 participants. The calculation was performed using IBM® SPSS® Sample Power® Release 3.0.1.35.

Digital model creation

A mandibular stone cast representing an edentulous arch served as the initial model. Thiscast was scanned using a desktop scanner (Medit T310, Seol, South Korea)and exported as an STL file. The STL file was imported into Blender Dental software (Blender Foundation, Amsterdam, The Netherlands) for digital model creation. Due to suboptimal cast ridge characteristics (insufficient height, axial undercuts), a cast base was digitally added. Analogs (with a diameter of 4.10 mm and height of 11.83 mm) were virtually placed, ensuring an inter-canine distance of 24 mm. Following virtual wax-up and analog placement, the model base was hollowed to optimize material usage and reduce printing time.

The STL file of the modified virtual model was then exported to CHITUBOX 3D Slicer Software (Shenzhen, China). The software then sliced the model into individual layers, generating precise instructions for the 3D printer. The final model was subsequently printed using Model resin (Proshape Dental Model, Turky)via aLCD 3D printer (Creality Halot, China).Printed resin molds were fabricated with dimensions of 8 mm in height, 18 mm in width, and 8 mm in thickness.

Digital Bar Design

Two bone-level dental implants (Neobiotic, IS-II active, South Korea) with internal Morse taper connections and hexagonal internal surfaces for anti-rotation were placed in each printed cast. Implants with a diameter of 4 mm and a length of 10 mm were placed at a depth of 7 mm, leaving 3 mm of the implant surface exposed. The implants were positioned parallel to one another with an inter-implant distance of 14 mm, guided by a dental surveyor (Ney Surveyor, Dentsply, USA) to ensure precise alignment.

Two scan abutments (Neobiotic, IS scan body, D4, SCRP, South Korea) were screwed to the implants. Subsequently, an intraoral scan was performed using a desktop scanner (Medit T310, Seol, South Korea). The acquired STL files were imported into ExocadDentalCAD 3.1 software (Exocad, Gmbh, Rijeka, Croatia) for the design of a bar superstructure over the two implants.

For this study, two sets of six specimens were fabricated. The first set was produced using SLM 3D printing technique, while the second set was manufactured utilizing Combined digital analog technique.

I. Computer-aided manufacturing/ Additive technique (SLM) (Intervention group)

The 3D printing process commenced by importing the STL file of the bar design into Materialise Magics software (Materialise Magics 22.41 software, Belgium). Within this software, the bar design was rotated 90 degrees along all three axes (Y, X, and Z). Subsequently, the software automatically generated the necessary support structures via the "Support Generation" icon. The prepared build data was then sliced into individual layers, enabling the 3D printer to accurately fabricate the framework. The processed job file was subsequently transferred to the VULCANTECH VM120 3D printer (Scheftner Dental, Germany), utilizing Co-Cr Dental Alloy powder as the build material. Within the printer, a thin layer of Co-Cr powder was uniformly distributed across the build platform. A high-powered laser then meticulously scanned the 3D model data, selectively sintering the Co-Cr powder layer-by-layer. This iterative process of powder deposition and laser melting continued until the complete bar framework was successfully fabricated.

Support structures were meticulously removed from the printed bars using manual cutting tools, such as large abrasive stones, to prevent damage to the delicate framework. Subsequently, air blasting with 110-micron aluminum oxide abrasive particles was performed using a sandblasting machine (Renfert-Gmbh basic classic -Sand

Sandblaster, Germany) at a pressure of 2 bar, maintaining a 5-7 cm distance from the surface to remove the surface oxide layer. To further enhance surface smoothness, a secondary sandblasting step was implemented using finer particles (50-100 microns). Finally, the specimens were polished using a chorus abrasive stone, polishing wheel, and abrasive pastes to achieve a clean and smooth surface. [26]

II. Combined digital analog fabrication (Control group)

The framework design was imported into MILL BOX CAM software (MILLBOX, CIM SYSTEM, Milan, Italy), selecting the EMAR V2 machine and cad wax material. A PMMA fixture with dimensions of 98 × 20 mm was prepared and positioned. The "auto-mill" function was utilized on a five-axis CNC milling machine (ED5X, Emar, Egypt) to fabricate the wax pattern from a blank. This process involved simultaneous removal of material from both the occlusal and internal surfaces to eliminate undercuts.Then, the milled pattern was sprued and embedded in phosphate-bonded investment material using a vacuum mixer to ensure air bubble-free mixing. The invested mold was subjected to a staged burnout process in a furnace, reaching a final temperature of 900°C to remove the wax.

Co-Cr alloy type 5 (KERA®C NPM Cobalt based dental casting bonding alloy, Germany) was melted in a preheated crucible in a centrifugal casting machine (Induction casting machine FORNAX 35E®, BEGO, Bremen, Germany). The molten metal was injected into the mold under high speed. After solidification, the investment was removed to expose the underlying metal bars, then the bar surfaces were meticulously finished and polished to achieve a precise fit. The sprue was subsequently removed using cutting and grinding tools. To eliminate impurities and oxides, the bars were subjected to sandblasting with 250-micron abrasive aluminum oxide particles (Dentify GmbH, Germany) for 60-90 seconds using a sandblasting machine at a pressure of 4 bar and a working distance of 3-4 cm. The bar surfaces were then refined further through finishing and polishing procedures to achieve the desired fit, resulting in the final cast with the finished bars.

Marginal Fit evaluation

The fabricated bars were precisely adapted to the implants via their internal connections, and the abutment screws were secured with a torque of 30 N using a dynamic torque wrench, in accordance with the manufacturer's instructions.All implants were subsequently subjected to vertical sectioning utilizing a water jet-powered sectioning device (Isomet, Buehler, Germany). After sectioning, the implants were meticulously rinsed with distilled water and ethyl alcohol to remove any residual debris that might have interfered with the precise observation of the implant-abutment interface.

Microscopic examination of each sample was conducted utilizing a USB-digital microscope (U500x Digital Microscope, Guangdong, China) equipped with a 3-megapixel camera positioned vertically 3 cm above the specimens. Illumination was provided by 8 LED lamps with a high color rendering index (approximately 95%), adjusted manually. Images were captured at maximum resolution (1280 x 1024 pixels) using a fixed 40x magnification and transferred to a personal computer. ImageJ 1.43U software (Image J 1.43U, National Institute of Health, USA) was used for gap width analysis. Prior to analysis, system calibration was performed using a ruler to convert pixel values to microns. For each specimen, images were acquired at three equidistant landmarks along the buccal, proximal, and lingual margins. At each landmark, morphometric measurements were repeated three times.

Statistical analysis:

Statistical analyses were conducted using SPSS 20®, GraphPad Prism®, and Microsoft Excel 2016. Kolmogorov-Smirnov and Shapiro-Wilk tests were used to evaluate the normality of the data.Standard deviation (SD) values are used to represent all quantitative data. Comparing the results of SLM-fabricated and traditionally cast specimens was done using paired t-tests. Repeated Measures ANOVA was utilized to assess differences among the various surface treatments within each group.

Results:

Evaluation of marginal fit:

I. Comparison between cast and 3D printed:

Marginal fit was assessed using a paired t-test. Statistically significant differences were observed between cast and SLM groups. The cast group demonstrated superior marginal misfit on the buccal surface (56.05 ± 7.65 µm vs. 34.19 ± 6.03 µm, p=0.003). While the cast group exhibited slightly lower values on the lingual surface (39.55 ± 4.94 µm) compared to the SLM group

(40.42 ± 5.55 µm), this difference was not statistically significant (p=0.81). Similarly, the cast group showed higher values on the proximal surface (54.39 ± 8.25 µm) compared to the SLM group (45.17 ± 7.62 µm), but this difference was not statistically significant (p=0.08). Overall, the cast group exhibited significantly more marginal misfit (50.00 ± 2.62 µm) compared to the SLM group (39.93 ± 4.71 µm) (p=0.002)**(Table 1, Figure 1).**

Table (1): Marginal fit of conventional cast and SLM regarding buccal, lingual, proximal, and overall, comparison between conventional cast and 3DP using Paired t test.

	Conventional Cast		3DP		Paired Differences					t	df	P value
					Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
	Mean	Standard Deviation	Mean	Standard Deviation				Lower	Upper			
Buccal	56.05	7.65	34.19	6.03	21.85	9.78	3.99	11.59	32.11	5.47	5	0.003*
Lingual	39.55	4.94	40.42	5.55	-0.87	8.24	3.36	-9.52	7.77	-0.26	5	0.806
Proximal	54.39	8.25	45.17	7.62	9.22	10.56	4.31	-1.85	20.30	2.14	5	0.085
Overall	50.00	2.62	39.93	4.71	10.07	3.92	1.60	5.95	14.19	6.28	5	0.001*

**Significant difference as P ≤ 0.05.*

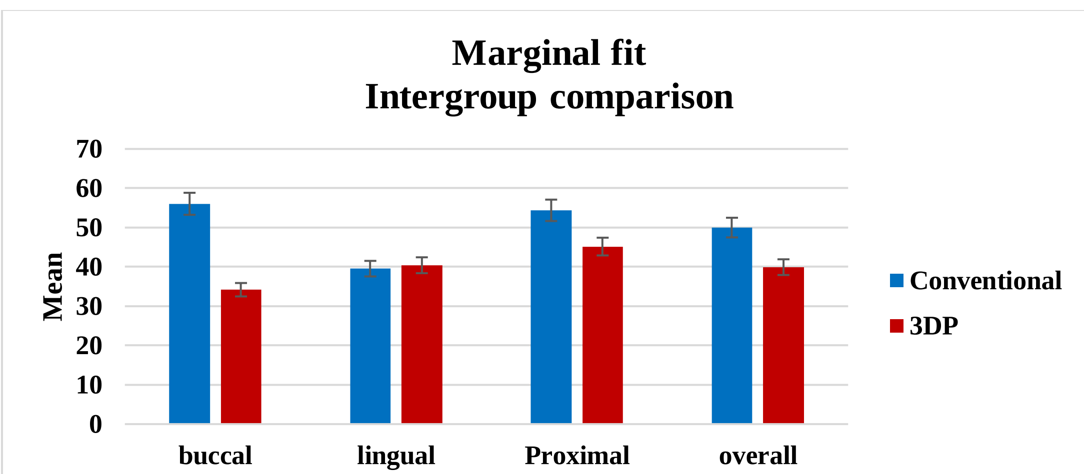

Figure (1): Bar chart showing comparison between marginal fit of conventional cast and SLM regarding buccal, lingual, proximal, and overall.

II. Comparison between surfaces:

Marginal fit was evaluated on buccal, lingual, and proximal surfaces of both cast and SLM groups. Repeated Measures ANOVA revealed significant surface-related variations in marginal fit within each group. In the cast group, the lingual surface exhibited the least favorable fit (39.55 ± 4.94 µm), while no significant differences were observed between the buccal (56.05 ± 7.65 µm) and proximal (54.39 ± 8.25 µm) surfaces. In the SLM group, the buccal surface demonstrated the most favorable fit (34.19 ± 6.03 µm), while the proximal surface exhibited the least favorable fit (54.39 ± 8.25 µm). In the SLM group, no significant differences were observed between the lingual (40.42 ± 5.55 µm) and other surfaces **(Table 2, Figure 2)**.

Table (2): Marginal fit of conventional cast and SLM regarding buccal, lingual, proximal, and overall, comparison between surfaces using Repeated Measures ANOVA test followed by Tukey`s Post Hoc test

	Buccal		Lingual		Proximal		P1	P2	P3	P value
	M	SD	M	SD	M	SD				
Conventional cast	56.05 a	7.65	39.55 b	4.94	54.39 a	8.25	0.02*	0.94	0.05*	0.01*
3DP	34.19 a	6.03	40.42 ab	5.55	45.17 b	7.62	0.14	0.01*	0.51	0.03*

**Significant difference as P ≤ 0.05, different letters at the same row mean significant difference at P<0.05*
P1: comparison between buccal and lingual. P2: comparison between buccal and proximal.
P3: comparison between lingual and proximal.

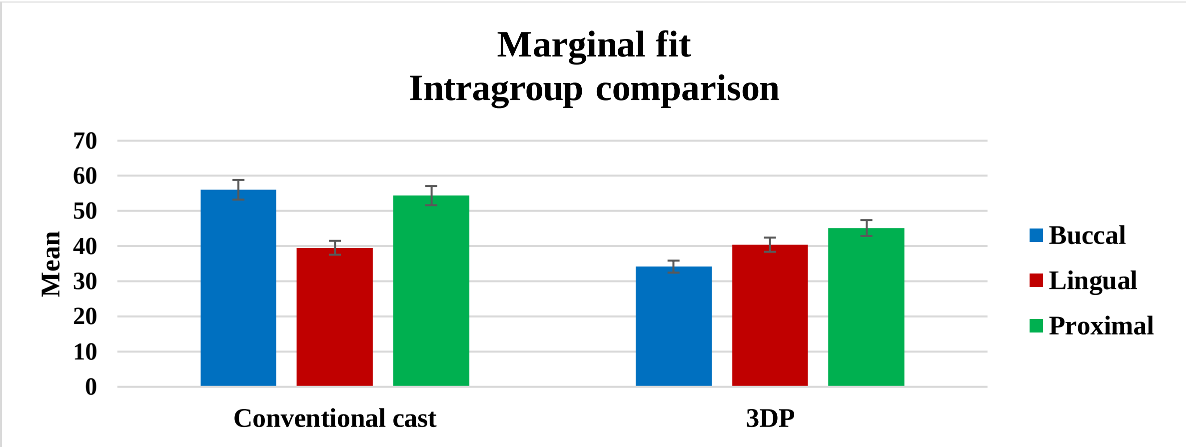

Figure (2): bar chart showing intragroup comparison regarding marginal fit of conventional cast and SLM.

Discussion:

The customization of bar-supported overdentures represents a notable advancement in prosthodontics, aimed at enhancing stability, retention, and patient comfort. Utilizing precision attachments, this modality supports dentures via remaining natural teeth or dental implants. Its primary objective is to optimize functional and aesthetic outcomes for patients, particularly those with compromised oral health or financial limitations that preclude extensive restorative treatments.[27]

Casting techniques for bar implant supported over denture fabrication, while established, have several limitations. These include the technique complexity, susceptibility to errors, and the need for high levels of technical skill. These factors can contribute to difficulties during bar fabrication and adjustment, as well as increased weight and bulk of the final prosthesis, potentially compromising patient comfort and retention. Casting errors, such as distorted impressions, inaccurate block out and waxing, processing errors, and inadequate metal/acrylic finishing, can result in improper seating and negatively impact prosthesis outcomes. Additionally, conventional methods are associated with high costs, lengthy fabrication times, and potential patient discomfort. Given these drawbacks, there is a strong need to explore alternative approaches to over denture prosthesis fabrication that may offer improved efficiency, accuracy, and patient outcomes.[28]

In contrast, CAD/CAM technologies offer a promising alternative fabrication technique. Both subtractive and additive manufacturing present advantages over casting, including improved accuracy, shorter fabrication times, reduced human error and material waste, easier transportation of digital files, and repeatability through file storage.[29]

Laser melting has emerged as a promising technique for dental application its ability to fabricate complex and precise RPD frameworks and bars supported implants from metal alloys offers substantial advantages over casting fabrication methods. Due to its dependence on CAD designs, SLM enables the production of highly accurate prostheses that closely conform to individual patient oral anatomy. This precision minimizes the need for chairside adjustments.[30]

Despite recent advancements in CAD/CAM technology, limited research exists comparing the fit accuracy of different implant-supported prosthesis fabrication techniques. Thus, the present study aimed to assess evaluate the marginal fit of digitally constructed Co-Cr bar on mandibular with two implant-supported over denture using SLM technique to be considered as reliable alternatives to casting methods in over denture prosthesis.

Given the critical importance of the abutment-implant interface in ensuring the stability and long-term success of implant-supported restorations, it is imperative to thoroughly investigate the impact of different manufacturing processes on the internal fit and accuracy of this interface. While acknowledging that achieving a perfect, zero-gap fit between implant and abutment is technically unattainable due to inherent limitations in manufacturing precision, the presence of micro gaps and the associated potential for micro leakage remains a significant clinical concern. Consequently, these micro gaps have been measured using a variety of methods, such as direct visualization, digital microscope analysis, and micro tomography. Therefore, the marginal gap of the bar-supported overdenture was assessed using digital microscope. [25]

This study employed a universal testing machine equipped with Instron® Bluehill Lite software. This choice was driven by the software's significant advantages, which include high-resolution data acquisition and a comprehensive suite of tools for precise stress-strain curve analysis. The precise determination of important mechanical properties like modulus of elasticity, yield strength, and ultimate tensile strength is made possible by these analytical capabilities. [31]

According to the finding of the present study, the nullhypothesis was rejected, which posited that no statistically significant differences were observed in the marginal fit of Co-Cr customized bars fabricated using the different manufacturing techniques.

The finding of this study was consistent with a previous study by**Nassar & Fateen (2023)**[25], which demonstrated a significant difference in marginal misfit between different fabrication methods. The highest mean marginal misfit was observed in conventionally cast Co-Cr bars (7.95 ± 2.21 μm), followed by SLM-fabricated bars (4.98 ± 1.73 μm). The lowest mean marginal misfit was observed in milled Co-Cr bars (3.22 ± 0.75 μm).

Nevertheless, the finding of our study was contrast to the results of**Fernández et al. (2014)**[32] in vitro study on Co-Cr custom-made abutments with external hexagonal connections. While they also observed the least marginal misfit in milled abutments, their investigation revealed no statistically significant difference between printed and cast abutments, unlike our findings. This discrepancy may be attributed to several factors, including variations in manufacturing techniques, material properties, implant-abutment interface designs, and evaluation methodologies employed in each study.

Previous studies have established that microgaps of less than 50 µm in implant-supported overdentures are generally considered clinically acceptable [33], [34], [35], [36]. Adherence to these established parameters is critical for achieving optimal prosthesis fit, stability, and long-term success. Factors such as manufacturing processes, implant system selection, and abutment torque can significantly influence the microgap size [37]. In this study, the marginal fit of all tested groups, including both 3D-printed Co-Cr and casting manufactured Co-Cr, fell within the clinically acceptable range with mean values of 39.93 ± 4.71 µm and 50.00 ± 2.62 µm, respectively. While statistically significant differences were observed, their clinical relevance may be limited.

The microgaps observed in the SLM group (39.93 ± 4.71 µm) may be attributed to the inherent characteristics of the SLM process. Previous studies have reported that laser sintering can introduce distortions and porosity within the 3D-printed structure.[38], [39] These imperfections can result in rougher interfaces between the bar and the implant, potentially leading to increased microgaps and hindering the achievement of a complete passive fit.

The observed microgap value of 50.00 ± 2.62 µm in the casting group may be attributed to the inherent limitations of the casting process. According to the previous studies, when Co-Cr dental alloys made by casting, milling, and sintering methods are evaluated radiographically, it typically reveals minimal porosities in specimens produced by milling and sintering methods, whereas cast specimens frequently exhibit gross porosities. This phenomenon can be partially explained by the significant expansion of investment materials during the casting process, which can potentially induce distortions and adversely affect the implant-abutment fit.[40], [41]

This study, in conjunction with prior research, emphasizes the substantial advantages of digital fabrication techniques for the production of bar-supported over dentures. By mitigating the inherent inaccuracies and inefficiencies associated with traditional casting methods, digital fabrication enables a more precise and efficient approach to bar manufacturing. This advancement holds the potential to enhance both the fit and function of the fabricated bars, ultimately leading to improved patient satisfaction and clinical outcomes.

This in vitro study has several limitations. Firstly, it focused solely on internal implant connections, excluding external connections from the investigation. Future studies should explore the influence of different implant connection types, including both internal and external designs, on marginal fit. Secondly, the study utilized a vertical cross-sectioning technique to assess marginal fit, which may not comprehensively evaluate the entire geometry of the internal fit due to the limited number of assessment points. Cross-sectioning itself may also have introduced some degree of specimen damage. Thirdly, the study did not investigate the effects of cyclic loading on marginal fit. In conclusion, while this study offers valuable insights into marginal fit, further investigations are necessary to assess the influence of marginal misfit on biomechanical performance and to determine its clinical relevance in vivo studies.

Conclusion:

Within the limitations of this in vitro study, this study demonstrated that both SLM and casted Co-Cr bars exhibited clinically acceptable marginal fit. However, SLM-fabricated bars demonstrated superior marginal fit at the implant-abutment interface in comparison to cast bars. These findings highlight the potential advantages of SLM technology in achieving high-precision and customized bar designs.

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Conflict of interest

The authors declare that they have no conflicts of interest relevant to the subject matter of this article.

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