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Research article

Influence of impression method and shoulder design on the marginal adaptation of CAD/CAM nanoceramic resin onlay restorations

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ABSTRACT

Objective: This in-vitro study investigates the influence of two different impression techniques and two shoulder designs on the marginal adaptation of computer-aided design/computer-aided manufacturing restorations.
Methods: Forty mandibular first premolars were cast into dental arch models for this in vitro study. Fragile cusps and concavities on the mesial–buccal–occlusal surfaces were treated, with 2 mm of the occlusal surface removed. Teeth were categorised into two groups based on shoulder preparation. Digital scanning using a 3Shape 3D scanner identified them further for allocation into conventional and digital impression subgroups. The restorations were created from nano-ceramic resin blocks using prescribed guidelines. Microscopic evaluation assessed the restoration's marginal adaptation, with data analysed using SPSS 27.0. The level of significance was set at $p \leq 0.05$.
Results: Digital intraoral scanning consistently demonstrated smaller marginal gaps than the traditional impression method, regardless of shoulder preparation, with the differences being statistically significant ($p < 0.05$). Furthermore, shoulder preparation significantly reduced the marginal gaps in both the digital and traditional impression groups ($p < 0.05$).
Conclusions: The onlay preparation design with a shoulder led to restorations with improved marginal adaptation compared with the design with no shoulder. Direct digital impression techniques produced restorations within a better marginal discrepancy than traditional impressions.

1. Introduction

The rapid advancements in computer-aided design/computer-aided manufacturing (CAD–CAM) technologies have reshaped the landscape of modern dentistry, offering a myriad of benefits, such as increased efficiency, precision and predictability, in dental restoration procedures [1]. At the heart of this revolution lies the persistent pursuit of achieving an optimal fit, particularly at the

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restoration's margins, which holds significant implications for the overall clinical success and longevity of dental restorations [2].

Marginal adaptation, the seamless transition between the restoration and the tooth structure, remains a critical determinant in preventing secondary complications, such as microleakage, recurrent caries and postoperative sensitivity. An impeccable marginal fit not only enhances the esthetic appeal but also minimises bacterial ingress, which can compromise the health of the periodontal tissues and underlying dental pulp [1,3]. However, achieving this ideal fit often presents various challenges that involve numerous factors, such as material choice and procedural techniques [4].

Previous studies have investigated the influence of various factors on the marginal adaptation of dental restorations, such as the type of CAD–CAM system used [5], the restorative material [6] and the preparation design [7]. However, limited research has focused on the combined effect of impression techniques and shoulder designs on the marginal adaptation of CAD–CAM restorations.

This study aims to bridge this gap by evaluating the impact of two preparation designs (with and without shoulder) and both direct and indirect digital impression methods on the marginal adaptation of CAD–CAM onlay restorations. By investigating the interaction between these factors, we provide valuable insights that can guide clinicians in optimising their restorative procedures and achieving superior marginal adaptation.

The study is underpinned by two primary assumptions: first, that the preparation design significantly affects the marginal discrepancy of CAD–CAM onlays; and second, that there is a distinguishable difference in the marginal discrepancy of onlays when using digital impression techniques versus traditional impression techniques.

2. Materials and methods

2.1. Material selection

For this in-vitro study, a total of 40 mandibular first premolars were collected from patients undergoing orthodontic treatment at the Southern Medical University Shenzhen Stomatology Hospital (Pingshan). All extracted teeth were preserved in a saline solution.

The study received approval from the hospital's institutional review board (202304A).

The sample size was calculated based on a power analysis using data from a pilot study, with a power of 80 % and a significance level of 0.05. The calculation indicated that a minimum of 10 specimens per group was required to detect significant differences in marginal adaptation between the groups.

2.2. Tooth preparation

1) The extracted mandibular first premolar, together with the resin tooth, was cast in plaster to make 40 mandibular dental arch models, each with one extracted premolar.
2) Preparation site selection: the mesial–buccal–occlusal surfaces of the extracted teeth were chosen. Concavities in the axial wall of the lesions were eliminated, and fragile cusps with thin walls were reduced, ensuring that all line angles were rounded and smoothened to a blunt shape.
3) Preparation process: approximately 2 mm of the occlusal surface was removed, ensuring that the cavity outlines presented non-sharp edges and a small-radius curvature. Additionally, the boundaries of the outlines were made distinct. During preparation, attention was paid to the thickness of the tooth's lateral walls, and its internal structure was rounded off. This ensured that following preparation, the margins, walls and floor of the cavity were visible from the occlusal surface without any obstructions.
4) Experimental grouping: based on the method of tooth preparation, the experimental teeth were divided into two groups using a random number table. The first group of 20 specimens underwent conventional shoulder preparation, whereas the second group of 20 specimens did not undergo shoulder preparation (Figs. 1 and 2).

2.3. Fabrication of restorations

Upon completion of the tooth preparation, 3Shape 3D digital scanning software (3Shape A/S, Copenhagen, Denmark) was used to assess line angles and the degree of convergence and to detect the presence of any undercuts. Subsequently, these experimental specimens were further sub-grouped: in each group, 10 samples underwent conventional impression-taking, while 10 used digital

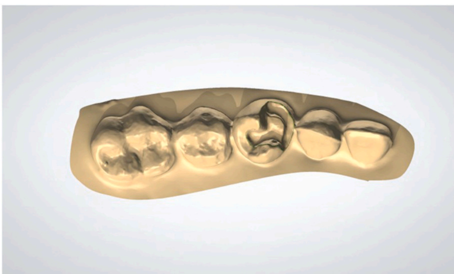

Fig. 1. Conventional preparation with shoulder margin.

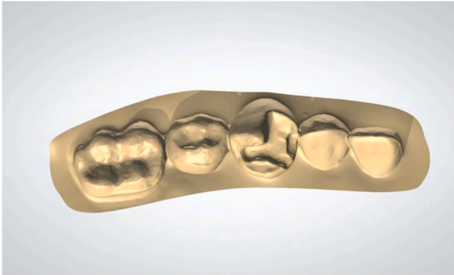

Fig. 2. Modified preparation without shoulder margin.

intraoral scanning. For the groups adopting the conventional impression method, polyether silicone rubber (3M, US) was employed for impression-taking. For the digital scanning group, direct intraoral scanning was performed to create the model (Table 1).

The 3Shape 3D CAD software was used to design the restorations. The CAD parameters were based on the manufacturer's recommended design guidelines, which included a radial thickness of >1.5 mm, an occlusal depth of >2 mm, die spacer settings at 100 µm, adhesive margin discrepancies at 50 µm and a margin depth of 120 µm. The restorations were fabricated using nanoceramic resin blocks (Lava 3M, US), with the aid of a milling device (Lava CNC 500, 3M, US).

2.4. Evaluation criteria

To thoroughly assess the marginal adaptation of the restorations, each restoration was first precisely positioned onto the corresponding tooth and secured using a specific resin (Ivoclar Vivadent, Liechtenstein). Following this, a microscope (Leica, Germany) was employed to magnify and inspect the marginal areas at 50 × magnification, and relevant image data were captured.

The absolute marginal gap was measured using a direct view technique. The specific evaluation sites included the following: (1) the mesial part, encompassing the mesiobuccal side, mesiogingival edge and mesiolingual side; (2) the occlusal surface, primarily the occlusolingual and occlusobuccal sides; and (3) the buccal part, including the buccomesial, buccogingival edge and buccodistal.

A direct view technique was adopted to evaluate the marginal adaptation because it allows for a more accurate assessment of the absolute marginal gap. This technique provides a clear, unobstructed view of the restoration margins, enabling precise measurements and minimising potential errors associated with indirect methods, such as replica techniques or sectioning. To ensure data accuracy, the Image-pro plus 6.0 software (Media Cybernetics, US) was employed for three independent measurements at each designated site. All collected data were subsequently inputted into SPSS 27.0 software (IBM, US) for in-depth statistical analysis.

2.5. Statistical analysis

The data were analysed using the SPSS 27.0 software. Descriptive statistics, including means and standard deviations, were calculated for each group. The Shapiro–Wilk test was used to assess the normality of the data distribution. As the data were normally distributed, independent sample *t*-tests were employed to compare the marginal discrepancies between the traditional impression and digital intraoral scanning groups, as well as between the shoulder preparation and no-shoulder preparation groups. The level of significance was set at $p < 0.05$.

3. Results

3.1. Statistical analysis of the obtained data was approached from two perspectives, as follows

1) Method of model data acquisition: upon comparing the different methods of model data acquisition, the study found that the digital intraoral scanning technique exhibited superior performance in terms of marginal gaps, significantly smaller than the traditional impression method. This difference was pronounced in both situations, whether shoulder preparation was performed or not, and held statistical significance ($p < 0.05$) (Table 2).
2) Influence of shoulder preparation: in both the digital and traditional impression groups, shoulder preparation notably reduced the marginal gaps of the restorations; this was a statistically significant result ($p < 0.05$) (Table 3).

Table 1
Experimental grouping.

Tooth Preparation Method	Number of Samples	Impression Method	
		Traditional Impression	Digital Scanning
Shoulder Preparation Group	20	10	10
No Shoulder Preparation Group	20	10	10

Table 2
Differences in marginal adaptation between traditional impressions and digital intraoral scanning.

	Traditional Impression		
	Marginal Discrepancy of Restorations (μm)	Digital Intraoral Scanning	P Value
Shoulder Preparation Group	79.4 ± 12.7	58.0 ± 10.9	<0.001
No Shoulder Preparation Group	94.1 ± 16.6	69.1 ± 13.8	0.002

4. Discussion

The present study's findings underscore two critical elements that influence the marginal adaptation of CAD–CAM dental restorations: onlay preparation design and the method of impression-taking.

Regarding the onlay preparation design, our data aligns with previous literature suggesting that definitive finish lines, such as those provided by the shoulder design, can aid in enhanced marginal adaptation [8,9]. The shoulder design inherently offers a more distinguishable and pronounced margin, which could simplify the milling or fabrication process in CAD–CAM restorations [2,10]. This clarity may account for the reduced discrepancies at the margins, minimising potential microleakage and subsequent risks, such as secondary caries or periodontal complications [11,12]. Conversely, designs without a clear shoulder may pose challenges in discerning the exact finish line, potentially contributing to larger marginal discrepancies.

The shift from traditional to digital impression methods has been one of the most transformative advancements in restorative dentistry over the last decade. Our findings further substantiate the growing body of evidence that highlights the superiority of digital impressions in capturing detailed and accurate tooth preparations [13]. Traditional impression techniques, although tried and tested, come with inherent challenges, such as dimensional instability of impression materials, potential for material-induced distortions and reliance on physical storage conditions, which could compromise accuracy [6,14,15]. Digital impressions, on the other hand, eliminate many of these variables, providing a more consistent and reliable method of capturing detailed tooth preparations. Furthermore, the immediate visualisation offered by digital methods enables clinicians to instantly assess the quality of the impression and retake it if necessary, ensuring optimal results [16,17].

Our findings regarding the superiority of digital impressions align with several recent studies. For instance, Mangano et al. [18] reported that digital impressions resulted in significantly lower marginal discrepancies compared to conventional impressions in their study of full-arch implant-supported restorations. Similarly, Kim et al. [19] found that intraoral scanners produced more accurate impressions than conventional methods for single crowns. However, it's worth noting that Ender et al. [20] reported no significant difference between digital and conventional impressions for full-arch scans, highlighting the need for continued research in this area.

The implications of our findings extend beyond the laboratory setting. The improved marginal adaptation achieved through digital impressions and shoulder preparation designs could potentially lead to better clinical outcomes. Reduced marginal discrepancies may result in decreased incidence of secondary caries, improved periodontal health, and enhanced longevity of restorations [21]. Moreover, the time efficiency and patient comfort associated with digital impressions could improve overall patient satisfaction and treatment acceptance [22].

5. Limitations and future research

Although our study provides valuable insights into the factors influencing the marginal adaptation of CAD–CAM dental restorations, it is essential to acknowledge its limitations. As an in-vitro study, the results may not fully reflect the clinical reality, where factors such as patient cooperation, moisture control and operator variability can impact the outcomes. Future research should focus on clinical studies that evaluate the long-term performance of CAD–CAM restorations with different impression techniques and shoulder designs. Additionally, incorporating advanced digital analysis methods, such as 3D scanning and superimposition, could provide more precise and comprehensive assessments of marginal adaptation.

In summary, although our study provides compelling evidence on the factors influencing the marginal adaptation of CAD–CAM dental restorations, it is imperative to view these findings in the context of individual clinical situations and the ever-evolving landscape of restorative dentistry.

6. Conclusions

Based on the findings of this in-vitro study, the following conclusions were drawn. First, the onlay preparation design with a

Table 3
Impact of shoulder preparation on the marginal adaptation of restorations.

	Marginal Discrepancy of Restorations (μm)		
	Shoulder Preparation Group	No Shoulder Preparation Group	P Value
Traditional Impression	79.4 ± 12.7	94.1 ± 16.6	0.039
Digital Intraoral Scanning	58.0 ± 10.9	69.1 ± 13.8	0.036

shoulder led to restorations with improved marginal adaptation compared with the design with no shoulder. Second, direct digital impression techniques produced restorations within a better marginal discrepancy than traditional impressions.

Ethics approval and consent to participate

This study was conducted in accordance with the Declaration of Helsinki and approved by the ethics committee of Southern Medical University Shenzhen Stomatology Hospital(Pingshan)(No.202304A).

Written informed consent was obtained from all participants.

Consent for publication

Not applicable.

Availability of data and materials

Data will be made available on request.

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CRediT authorship contribution statement

Muyue Li: Writing – review & editing, Writing – original draft, Project administration, Methodology, Formal analysis, Data curation, Conceptualization. **Ben Ma:** Writing – review & editing, Writing – original draft, Project administration, Methodology, Formal analysis, Conceptualization. **Zhuanyuan Zhou:** Writing – review & editing, Writing – original draft, Project administration, Methodology, Formal analysis. **Wei Liu:** Writing – original draft, Project administration, Formal analysis.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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N/A.

Abbreviations

CP	Conventional preparation
CEREC	Chairside Economical Restoration of Esthetic Ceramics
CAD-CAM	Computer-Aided Manufacturing
MP	Modified preparation
MBO	Mesial-buccal-occlusal
PVS	Polyvinyl siloxane

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