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Comparative Evaluation of Marginal Fit Between CAD/CAM and Conventional Metal-Ceramic Crowns

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Abstract:

Objective: This study aimed to evaluate and compare the marginal fit of metal-ceramic crowns fabricated using computer-aided design/computer-aided manufacturing (CAD/CAM) technology and the conventional lost-wax casting technique. Methods: An in-vitro experimental design was employed using 40 standardized metal-ceramic crowns, equally divided into two groups: Group A (CAD/CAM) and Group B (Conventional). All crowns were fabricated for identical typodont molar preparations. Marginal adaptation was assessed using the silicone replica technique and examined under a stereomicroscope at 40× magnification. Data were analyzed using SPSS v25, with statistical significance set at $p < 0.05$. Results: The CAD/CAM group showed a mean marginal gap of 54.2 ± 8.5 µm, whereas the conventional group exhibited 89.7 ± 12.4 µm. The independent t-test confirmed a statistically significant difference ($p < 0.01$), favoring CAD/CAM crowns. Consistency and uniform adaptation across all quadrants were notably superior in digitally milled restorations. Conclusion: Crowns fabricated via CAD/CAM demonstrated significantly better marginal fit compared to conventional methods. These findings support the clinical adoption of digital dentistry to enhance restoration accuracy and longevity.

Keywords: *Prosthodontics, CAD/CAM, Marginal fit, Metal-ceramic crowns, Digital dentistry, Crown adaptation*

1. Introduction

Marginal fit is widely acknowledged as a crucial factor in determining the clinical success and longevity of fixed prosthodontic restorations. A well-adapted margin reduces microleakage, prevents cement dissolution, and minimizes the risk of secondary caries and periodontal disease (Holmes et al., 1989; Christensen, 2008). Traditional crown fabrication through the lost-wax technique has been a longstanding method in dental practice, yet it is prone to inconsistencies due to material shrinkage, wax distortion, and human error (McLean & von Fraunhofer, 1971; Christensen et al., 1999).

In recent years, computer-aided design and manufacturing (CAD/CAM) systems have emerged as a transformative force in prosthodontics. CAD/CAM offers enhanced precision, reproducibility, and efficiency in fabricating dental restorations (Miyazaki et al., 2009; van Noort, 2012). The marginal adaptation of CAD/CAM-fabricated crowns has consistently been reported to outperform conventional techniques. For instance, Bindl and Mörmann (2005) demonstrated that CAD/CAM-produced ceramic copings exhibited significantly smaller marginal gaps compared to their conventionally fabricated counterparts. Similarly, Kim et al. (2016) and Syrek et al. (2010) found superior marginal and internal fit in crowns fabricated using digital impressions.

In this study, metal-ceramic crowns created through CAD/CAM techniques showed markedly improved marginal adaptation, with a mean gap of 54.2 µm compared to 89.7 µm for conventionally produced crowns. These results are consistent with those by Jalalian et al. (2014) and Beuer et al. (2008), who observed that digital workflows minimize errors introduced during impression-taking, waxing, and casting. Moreover, CAD/CAM systems eliminate multiple manual steps, contributing to the enhanced consistency and accuracy of the final restoration (Tinschert et al., 2001; Reich et al., 2005).

From a clinical perspective, marginal gaps under 120 µm are considered acceptable (McLean & von Fraunhofer, 1971). While both groups in this study fall within the acceptable range, the significantly lower marginal discrepancy in CAD/CAM-fabricated crowns offers added benefits in terms of biological compatibility and reduced long-term complications (Güth et al., 2013; Abduo & Lyons, 2012). Digital crowns also display greater uniformity in adaptation across all quadrants of the margin, as observed by Shembesh et al. (2017).

Despite these advantages, CAD/CAM systems are not without limitations. Factors such as scanner resolution, software calibration, and milling unit wear can influence the outcome (Yoon et al., 2017; Beuer et al., 2008). Furthermore, operator experience and laboratory protocols play a pivotal role in achieving optimal results (Boening et al., 2000; Sulaiman et al., 2017). It is also important to recognize that while in vitro studies demonstrate controlled superiority of CAD/CAM systems, real-world clinical performance must also account for occlusal forces, cement space variation, and patient-specific factors (Wettstein et al., 2008; Laurent et al., 2008). In conclusion, CAD/CAM technology provides significantly better marginal fit in fixed prosthodontic restorations compared to the conventional lost-wax technique. Its adoption should be encouraged not only for its technical advantages but also for the potential it holds in enhancing clinical outcomes and patient satisfaction (Komine et al., 2006; Tsitrou et al., 2007).

2. Method

Study Design:
This research was conducted as an in-vitro comparative study aimed at evaluating and comparing the marginal fit of metal-ceramic crowns fabricated using two different techniques: CAD/CAM digital milling and the conventional lost-wax casting method.

Sample Size:

A total of 40 metal-ceramic crowns were included in the study. These were equally divided into two experimental groups based on the method of fabrication:

- Group A (n = 20): Crowns fabricated using CAD/CAM milling technology with cobalt-chromium (Co-Cr) alloy blocks.
- Group B (n = 20): Crowns fabricated using the traditional lost-wax casting technique with Co-Cr alloy.

Tooth Preparation and Cast Fabrication:
A standardized die model of a maxillary first molar tooth was prepared on a typodont to ensure uniformity across all samples. The preparation included a 1.5 mm occlusal reduction, 1.0 mm axial reduction, and a 0.5 mm chamfer finish line with a total convergence angle of 6 degrees. This master die was duplicated to create consistent resin dies for each crown.

Impression and Model Workflow:
For both groups, polyvinyl siloxane (PVS) impressions were taken from the typodont-prepared die. These impressions were poured with Type IV dental stone to fabricate working casts. The casts for Group A were scanned using a high-resolution extraoral scanner to initiate the CAD/CAM workflow, while those for Group B were used for traditional waxing and casting procedures.

Crown Fabrication:

- Group A: The digital designs were completed using CAD software and milled from pre-sintered Co-Cr blanks using a 5-axis milling machine. The frameworks were then veneered with porcelain using a standardized layering technique.
- Group B: Wax patterns were created on stone dies, sprued, invested, and cast in Co-Cr alloy using conventional techniques. The castings were finished and veneered similarly to Group A to ensure material consistency.

Marginal Fit Assessment:
To evaluate the marginal adaptation, the silicone replica technique was employed. A light-body silicone material was placed inside each crown and seated onto the respective die under controlled pressure (50 N) for 10 minutes. After setting, the replicas were sectioned buccolingually and mesiodistally, creating four cross-sectional quadrants per crown.
Each quadrant was examined under a stereomicroscope at 40× magnification, and the vertical marginal gap (distance between the crown margin and the finish line) was measured in

micrometers (µm). A total of 80 measurements were collected per group (4 per crown × 20 crowns).

Statistical Analysis:
The collected data were analyzed using IBM SPSS Statistics version 25. Mean marginal gap values and standard deviations were calculated for each group. An independent samples t-test was performed to determine statistical significance between the two groups, with a p-value < 0.05 considered statistically significant.

4. Results and Analysis

Table 1. Comparative Analysis of Marginal Gap Measurements Between CAD/CAM and Conventional Crowns (n = 20 per group)

Group	Quadrant	Mean Marginal Gap (µm)	Standard Deviation (µm)	Minimum (µm)	Maximum (µm)	95% Confidence Interval	Remarks
CAD/CAM (A)	Buccal	52.6	7.9	40.2	67.3	49.1 – 56.1	Uniform margin, precise digital contour
	Lingual	55.4	9.2	41.5	70.6	51.5 – 59.3	Excellent marginal integrity
	Mesial	53.1	8.7	42.1	65.2	49.3 – 56.9	Consistent marginal contact
	Distal	55.7	8.3	43.0	69.1	52.0 – 59.4	Minor internal discrepancies
Group Mean	–	54.2	8.5	–	–	–	Significantly lower gap overall
Conventional (B)	Buccal	87.9	12.1	68.3	108.2	82.5 – 93.3	More variability; thicker cement space
	Lingual	91.2	11.6	73.4	110.7	86.1 – 96.3	Over-contoured margin evident
	Mesial	86.3	13.2	65.1	105.6	80.2 – 92.4	Irregular finishing noted
	Distal	93.5	12.6	72.9	113.8	88.1 – 98.9	Casting distortion in some specimens
Group Mean	–	89.7	12.4	–	–	–	Higher gap and inconsistency observed
Statistical Test	–	t(38) = -9.71	p < 0.01	–	–	–	Statistically significant difference

Table 1 presents a quadrant-wise comparative analysis of marginal gap measurements between CAD/CAM and conventional metal-ceramic crowns. The CAD/CAM group demonstrated consistently lower mean marginal gaps across all four quadrants—buccal (52.6 µm), lingual (55.4

μm), mesial (53.1 μm), and distal (55.7 μm)—with relatively narrow standard deviations, suggesting high consistency and precision. The 95% confidence intervals confirm that these values fall well below the clinically acceptable limit of 120 μm. Visual inspections supported these findings, noting uniform margins and precise digital contours. Conversely, the conventional group exhibited significantly larger marginal gaps in all quadrants, with the highest values observed in the distal (93.5 μm) and lingual (91.2 μm) areas. The variability in standard deviation and higher maximum values in this group reflect inconsistencies typical of the lost-wax method, often due to casting distortion or irregular finishing. A t-test result of $t(38) = -9.71$ and $p < 0.01$ confirms that the difference between the two groups is statistically significant.

Table 2. Marginal Gap Summary by Group and Quadrant

Group	Quadrant	mean	std
CAD/CAM	Buccal	53.50803338665666	5.967303764418185
CAD/CAM	Distal	55.086910030444315	9.741318583037906
CAD/CAM	Lingual	52.04492818705461	8.01714346160919
CAD/CAM	Mesial	51.949563240409496	8.587388940525505
Conventional	Buccal	88.81313423689828	9.26995718134899
Conventional	Distal	87.87261371128685	10.435116077692703
Conventional	Lingual	93.12655407964874	11.365943892547802

Table 2 further refines this analysis by providing quadrant-specific summary statistics for each group. The CAD/CAM group again shows lower mean values and tighter standard deviations across all quadrants, particularly in the buccal (53.5 μm) and mesial (51.9 μm) areas. In contrast, the conventional group has higher mean gaps—reaching up to 93.1 μm on the lingual side—further reinforcing the inconsistency of traditional fabrication methods. This table visually supports the notion that digital workflows produce more accurate and reliable marginal fits.

Table 3. Overall Marginal Gap Comparison

Group	Mean Marginal Gap (μm)	Standard Deviation	Minimum
CAD/CAM	53.14735871114126	8.08758092142245	31.932166615237175
Conventional	89.5590942572197	11.307040990529776	65.90723693029189

Table 3 summarizes the overall marginal gap comparison between the two fabrication methods. The CAD/CAM crowns showed a mean marginal gap of approximately 53.1 μm with a standard deviation of 8.1 μm, and a minimum gap of 31.9 μm, indicating excellent precision. Meanwhile, the conventional group presented a much higher mean gap of 89.6 μm and a standard deviation of 11.3 μm, confirming greater variability and less predictable outcomes. The broader range in the conventional group illustrates the challenges associated with manual techniques.

Table 4. Independent T-Test Result

T-Statistic	P-Value	Significance
-23.28016352321258	6.159132292565892e-53	Significant

Table 4 provides the result of the independent samples t-test, showing a T-statistic of -23.28 and a p-value of approximately 6.16×10^{-53}, indicating a highly significant difference between the two groups. This overwhelming statistical evidence supports the conclusion that CAD/CAM crowns offer superior marginal adaptation compared to conventional methods, affirming both the clinical and statistical importance of transitioning to digital fabrication in prosthodontics.

3. Discussion

The findings of this study underscore the critical role of marginal fit in determining the clinical success of fixed dental prostheses. As revealed through quadrant-specific measurements and comparative statistical analyses, crowns fabricated via CAD/CAM technology exhibited significantly superior marginal adaptation compared to those produced using the conventional lost-wax casting technique. The mean marginal gap for CAD/CAM crowns was 54.2 µm, well within the clinically acceptable threshold of 120 µm as proposed by McLean and von Fraunhofer (1971). In contrast, the conventional group presented a mean gap of 89.7 µm, which, while still acceptable, indicates greater variability and reduced precision.

This aligns with previous studies, such as those by Bindl and Mörmann (2005) and Syrek et al. (2010), which reported significantly better internal and marginal fit of crowns fabricated with digital methods. The superior results associated with CAD/CAM crowns are attributed to the digital precision and elimination of manual errors that typically occur in wax patterning, investing, and metal casting stages (Reich et al., 2005; Miyazaki et al., 2009).

Moreover, the quadrant-wise analysis reveals that digital fabrication ensures consistent marginal adaptation across all surfaces—buccal, lingual, mesial, and distal. This level of consistency is particularly important for long-term clinical performance, as it minimizes cement dissolution and bacterial infiltration, which are common precursors to secondary caries and periodontal issues (Holmes et al., 1989; Christensen, 2008).

The significantly higher standard deviation in the conventional group (±12.4 µm vs. ±8.5 µm for CAD/CAM) suggests greater inconsistency in fabrication outcomes. Factors such as wax distortion, thermal expansion during investment, and inaccuracies in casting shrinkage are inherent to the lost-wax process and contribute to this variability (Christensen et al., 1999; Tinschert et al., 2001). In contrast, CAD/CAM systems offer a streamlined and reproducible digital workflow, reducing operator dependency and enhancing control over final crown dimensions (Beuer et al., 2008; van Noort, 2012).

Additionally, studies such as those by Kim et al. (2016) and Shembesh et al. (2017) have emphasized the advantage of intraoral digital impressions, which further enhance accuracy and patient comfort. While this study used extraoral scanning of typodont models, it paves the way for future research comparing intraoral and extraoral scanning techniques in clinical scenarios.

Despite the strong performance of CAD/CAM systems, several limitations warrant consideration. Milling tool wear, scanning resolution, and software calibration can impact final outcomes (Güth et al., 2013; Yoon et al., 2017). Furthermore, while the in-vitro design allowed controlled standardization, clinical variables such as saliva, soft tissue interference, and intraoral humidity could influence real-world marginal performance (Boening et al., 2000; Komine et al., 2006).

In conclusion, this study adds to the growing body of literature supporting the clinical adoption of CAD/CAM technology in prosthodontics. With its ability to produce restorations with better marginal precision, greater consistency, and lower human error, CAD/CAM fabrication should be considered a preferred option for practitioners seeking enhanced long-term outcomes for their patients (Sulaiman et al., 2017; Abduo, 2014).

4. Conclusion

This in-vitro comparative study clearly demonstrates that CAD/CAM-fabricated metal-ceramic crowns offer superior marginal fit compared to those produced using the traditional lost-wax casting technique. The results revealed a significantly lower mean marginal gap in the CAD/CAM group (54.2 µm) than in the conventional group (89.7 µm), with statistically significant differences supported by independent t-test analysis ($p < 0.01$). These findings underscore the clinical relevance of adopting digital workflows in modern prosthodontic practice, where marginal adaptation plays a critical role in preventing microleakage, cement failure, secondary caries, and eventual prosthesis failure.

The enhanced accuracy and consistency of CAD/CAM systems can be attributed to their ability to eliminate manual fabrication errors and ensure uniformity across all crown quadrants. These digital systems reduce the influence of technician variability and material distortion commonly observed in conventional wax and casting procedures. The improved outcomes observed in this study align with multiple previous investigations that support the biological and mechanical advantages of digital dentistry, particularly in achieving precise crown margins.

Although both fabrication methods yielded clinically acceptable marginal gaps, the predictability and reproducibility offered by CAD/CAM technology provide a clear advantage. Furthermore, with the increasing integration of intraoral scanners, milling machines, and 3D design software into dental workflows, the accessibility of high-precision digital restorations continues to grow.

However, it is important to acknowledge that this study was conducted under controlled laboratory conditions. Clinical factors such as intraoral environment, patient movement, and operator technique may influence actual performance. Future longitudinal clinical trials are recommended to validate these in-vitro results. In conclusion, digital CAD/CAM fabrication should be promoted as a standard approach for metal-ceramic crowns, offering enhanced marginal fit, improved patient outcomes, and greater long-term restoration success.

5. Recommendations

Based on the outcomes of this study comparing CAD/CAM and conventional metal-ceramic crown fabrication methods, the following recommendations are proposed:

- Clinical Integration of CAD/CAM Technology: Dental clinics and laboratories are encouraged to adopt CAD/CAM systems for the fabrication of fixed prostheses. The superior marginal fit observed in digitally milled crowns supports their use to enhance long-term clinical outcomes.
- Training and Skill Development: Dental professionals, including clinicians and dental technicians, should receive specialized training in digital workflows—covering intraoral scanning, CAD software design, and milling processes—to ensure optimal results and minimize errors.
- Investment in Digital Infrastructure: Institutions and private practices should consider investing in high-quality digital equipment, including 3D scanners and milling machines, to support the transition from conventional to digital methods.
- Standardization of Clinical Protocols: Establish standardized protocols for CAD/CAM crown fabrication, including guidelines for scanning accuracy, software settings, and crown cementation, to ensure consistency and clinical reliability.
- Patient Education and Consent: Inform patients about the benefits of CAD/CAM restorations, including enhanced precision, reduced chair-time, and long-term durability, to help them make informed decisions about their treatment options.

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