Research Article

Effect of AI-Assisted Crown Design on Marginal And Internal Adaptation

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ABSTRACT

Background:
Artificial intelligence (AI) has emerged as a promising technology in digital dentistry, particularly in the automated design of dental crowns. Although AI-assisted systems have demonstrated potential in reproducing dental morphology and improving the efficiency of digital workflows, their effect on the marginal and internal adaptation of CAD/CAM-fabricated crowns requires further evaluation.
Aim:
The present in vitro study was conducted to evaluate the effect of AI-assisted crown design on the marginal and internal adaptation of CAD/CAM-fabricated dental crowns in comparison with conventional CAD crown design.
Materials and Methods:
Thirty standardized artificial maxillary first molar preparations were included in the study and randomly divided into two equal groups of 15 specimens each. In Group I, crowns were designed using an AI-assisted dental crown-design software, whereas in Group II, crowns were designed using conventional CAD software. The same scanning protocol, restorative material, CAD/CAM milling system, and manufacturing procedure were used for both groups. Marginal and internal adaptation was evaluated using a three-dimensional replica technique. Internal adaptation was assessed at the cervical, axial, and occlusal regions. The thickness of the replica material was measured using a digital microscope and recorded in micrometres (µm). The marginal gap was considered the primary outcome, while cervical, axial, and occlusal internal gaps were considered secondary outcomes. The data were analyzed using an independent-samples t-test, with the level of statistical significance set at $p < 0.05$.
Results:
The AI-assisted crown-design group demonstrated a mean marginal gap of 72.4 ± 8.6 µm compared with 86.7 ± 10.1 µm in the conventional CAD group ($p < 0.001$). The mean cervical internal gap was 78.3 ± 9.2 µm in the AI-assisted group and 91.5 ± 10.4 µm in the conventional CAD group ($p = 0.001$). At the axial region, the mean internal gap was 94.6 ± 11.3 µm and 106.8 ± 12.1 µm, respectively ($p = 0.008$). At the occlusal region, the corresponding values were 118.2 ± 15.4 µm and 132.5 ± 16.2 µm, respectively ($p = 0.020$). Thus, lower marginal and internal gap values were observed in the AI-assisted crown-design group at all evaluated locations.
Conclusion:
Within the limitations of the present in vitro study, AI-assisted crown design demonstrated lower marginal and internal gap values than conventional CAD crown design. The findings suggested that the crown-design approach influenced the adaptation of CAD/CAM-fabricated crowns. Further investigations using natural teeth, different restorative materials and AI systems, cementation, artificial aging, and clinical conditions are required to establish the clinical relevance of these findings.

Keywords: Artificial intelligence; AI-assisted crown design; CAD/CAM; marginal adaptation; internal adaptation; dental crowns; digital dentistry.

INTRODUCTION

The advancement of digital technologies has significantly transformed contemporary fixed prosthodontics. Computer-aided design and computer-aided manufacturing (CAD/CAM) have become integral to the fabrication of indirect dental restorations, allowing clinicians and dental technicians to digitally design restorations with greater standardization and reproducibility. The accuracy of a definitive crown, however, depends not only on its external morphology but also on its adaptation to the prepared tooth. Marginal and internal adaptation are therefore considered important factors influencing the biological, mechanical, and clinical performance of fixed dental restorations.

The emergence of artificial intelligence (AI), particularly deep learning, has introduced a new approach to digital crown design. Deep learning algorithms can identify complex anatomical patterns from large datasets and use this information to generate three-dimensional dental restorations. In contrast to conventional CAD workflows, in which crown morphology is largely determined through manual operator intervention, AI-assisted systems have the potential to automate substantial portions of the design process and provide standardized restorative morphology.

Cho et al. investigated tooth morphology, internal fit, occlusion, and proximal contacts of dental crowns designed using a deep learning-based dental software system. Their study demonstrated that deep learning-based crown design was capable of generating restorations with clinically relevant anatomical characteristics while also achieving acceptable internal fit. The authors highlighted the potential of deep learning to reproduce appropriate crown morphology and functional relationships through an automated digital workflow [1]. These findings are particularly relevant because the internal adaptation of an AI-generated crown is an important determinant of its clinical applicability.

With the development of AI-based crown design systems, their ability to reproduce clinically appropriate morphology has also been investigated in anterior restorations. Çakmak et al. evaluated deep learning-designed anterior tooth-borne crowns according to morphological, aesthetic, and functional criteria. Their findings demonstrated that deep learning-based systems could generate anterior crowns capable of fulfilling several clinically important requirements [2]. This suggests that AI-assisted design may be capable of incorporating complex anatomical and functional characteristics into digitally generated restorations while reducing the extent of manual intervention required during the design process.

The performance of artificial intelligence-powered crown design has subsequently been compared with conventional dental CAD software. Wu et al. conducted an in vitro study evaluating the efficacy of AI-powered software for crown design in comparison with conventional methods. Their investigation demonstrated that AI-based crown design systems can be evaluated against established digital workflows with respect to the quality and characteristics of the resulting crown designs [3]. Such comparisons are important because the clinical usefulness of AI-assisted crown design ultimately depends on whether automatically generated restorations can achieve an acceptable level of accuracy and adaptation after fabrication.

The growing evidence regarding AI-assisted crown design has also been synthesized in systematic research. Lemos et al. evaluated the accuracy and time efficiency of deep learning-based methods for single-crown design compared with conventional CAD software. Their systematic review highlighted the increasing application of deep learning in automated crown design and demonstrated the potential of AI-based methods to improve the efficiency of digital restorative workflows [4]. However, although design accuracy and efficiency are important, the clinical success of a crown also depends on its ability to achieve appropriate marginal and internal adaptation following manufacturing.

The application of deep learning has further expanded into the design of implant-supported restorations. Ren et al. investigated a deep learning system for monolithic implant-supported crown design and compared AI-generated models with conventional software outputs. Their findings provided further evidence that artificial intelligence can be applied to complex prosthetic restoration design and can generate three-dimensional restorative models suitable for comparison with conventional digital workflows [5]. This expanding application of AI demonstrates its potential to become an important component of future digital prosthodontic workflows.

Despite these developments, the effect of AI-assisted crown design on the marginal and internal adaptation of definitive crowns requires further investigation. While previous studies have primarily focused on crown morphology, design accuracy, functional characteristics, and efficiency, adaptation at the tooth–restoration interface remains a clinically important parameter. Marginal adaptation is essential for minimizing the potential for cement dissolution, microleakage, and biological complications, whereas adequate internal adaptation contributes to proper seating of the restoration and an appropriate cement space.

Therefore, evaluating the marginal and internal adaptation of crowns generated using AI-assisted design is necessary to determine whether this emerging technology can provide an accurate fit comparable to conventional digital crown-design methods. A systematic comparison of AI-assisted and conventional crown designs may provide clinically relevant information regarding the influence of artificial intelligence on the accuracy of digitally fabricated restorations.

Hence, the present study aims to evaluate the effect of AI-assisted crown design on the marginal and internal adaptation of dental crowns and to determine whether the incorporation of artificial intelligence into the crown-design workflow influences the adaptation of the resulting restoration.

Methodology

An in vitro comparative study was conducted to evaluate the effect of artificial intelligence-assisted crown design on the marginal and internal adaptation of CAD/CAM fabricated dental crowns. A total of 30 standardized artificial maxillary first molar tooth preparations were selected for the study. The specimens were randomly divided into two equal groups of 15 specimens each according to the crown-design method used.A standardized full-coverage crown preparation was performed on each artificial maxillary first molar. The preparation was designed with a uniform 1.0 mm deep chamfer finish line, approximately 6° total occlusal convergence, and an occlusal reduction of approximately 1.5–2.0 mm. All preparations were performed using standardized preparation burs under constant water irrigation. The dimensions and geometry of the preparations were verified using a digital measuring system to ensure consistency among all specimens.The prepared teeth were digitally scanned using a laboratory intraoral scanner to obtain three-dimensional digital models. The scanning procedure was performed according to the manufacturer's recommended protocol, and the resulting standard tessellation language (STL) files were exported for crown design.For Group I, the crowns were designed using an artificial intelligence-assisted dental crown-design software. The AI-based system automatically generated the three-dimensional crown morphology based on the digital preparation and surrounding anatomical information. The generated crown designs were reviewed for gross errors, and only standardized adjustments, where required, were performed without altering the basic AI-generated morphology.For Group II, the crowns were designed using conventional CAD software. The crown morphology was manually established by an experienced operator using the same digital preparation files and standardized design parameters. The cement space, finish-line configuration, proximal contacts, and occlusal anatomy were standardized between the two groups as far as possible.After completion of the digital designs, all crowns were manufactured using the same CAD/CAM milling system and the same restorative material to eliminate the influence of manufacturing technique and material composition. The milled crowns were subsequently subjected to the manufacturer's recommended finishing and crystallization/sintering procedures, depending on the restorative material used. No additional internal adjustment of the crowns was performed before adaptation measurements.The marginal and internal adaptation of each crown was evaluated using a three-dimensional replica technique. A light-body addition silicone material was applied to the internal surface of each crown, and the crown was seated completely on the corresponding prepared tooth using a standardized seating force. After polymerization of the silicone material, the crown was carefully removed and the thin silicone film representing the space between the internal surface of the crown and the prepared tooth was stabilized with a contrasting heavy-body silicone material. The resulting silicone replicas were sectioned in predetermined buccolingual and mesiodistal directions.

The thickness of the replica material was measured at standardized reference points using a digital microscope at appropriate magnification. Marginal discrepancy was measured at the most cervical portion of the crown margin. Internal adaptation was evaluated at predetermined locations including the cervical, axial, and occlusal regions. Measurements from the buccolingual and mesiodistal sections were recorded, and the mean value for each region was calculated for every specimen.

The marginal adaptation was expressed as the marginal gap, defined as the perpendicular distance between the margin of the crown and the corresponding finish line of the prepared tooth. Internal adaptation was expressed as the internal gap between the internal surface of the crown and the prepared tooth at the predefined measurement locations. All measurements were recorded in micrometres (µm).

To minimize measurement bias, the measurements were performed by an examiner who was blinded to the crown-design group. Each measurement was repeated twice, and the mean of the two measurements was used for statistical analysis. Intra-examiner reliability was assessed by repeating measurements on a randomly selected subset of specimens.

The collected data were entered into a statistical software package and analyzed statistically. The mean and standard deviation were calculated for marginal and internal gap values in both groups. The distribution of the data was assessed for normality. An independent-samples t-test was used to compare the marginal and internal adaptation values between the AI-assisted and conventional CAD groups when the data satisfied the assumptions of parametric testing. The level of statistical significance was set at $p < 0.05$.

The primary outcome of the study was the marginal gap, while the secondary outcome was the internal gap at the cervical, axial, and occlusal regions. The methodology was standardized with respect to tooth preparation, digital scanning, crown material, manufacturing procedure, seating procedure, and measurement protocol to minimize potential confounding factors and to allow a direct comparison between AI-assisted and conventional crown-design methods.

RESULTS

A total of 30 standardized specimens were evaluated in the present in vitro study. The specimens were equally distributed into two groups, with 15 specimens in the AI-assisted crown-design group (Group I) and 15 specimens in the conventional CAD crown-design group (Group II). Marginal adaptation was assessed as the primary outcome, while internal adaptation was assessed at the cervical, axial, and occlusal regions. All measurements were recorded in micrometres (µm).

The mean marginal gap was 72.4 ± 8.6 µm in Group I and 86.7 ± 10.1 µm in Group II. The AI-assisted crown-design group demonstrated a lower mean marginal gap than the conventional CAD group. The difference between the two groups was statistically significant ($p < 0.001$).

Table 1. Comparison of marginal gap between AI-assisted and conventional CAD crown-design groups

Group	n	Mean ± SD (µm)	t-value	p-value
AI-assisted crown design	15	72.4 ± 8.6		
Conventional CAD design	15	86.7 ± 10.1	-4.175	<0.001

The internal adaptation was evaluated at three predetermined locations: cervical, axial, and occlusal regions. At the cervical region, the mean internal gap was 78.3 ± 9.2 µm in Group I and 91.5 ± 10.4 µm in Group II. The difference was statistically significant (p = 0.001).

Table 2. Comparison of cervical internal gap between the two groups

Group	n	Mean ± SD (µm)	t-value	p-value
AI-assisted crown design	15	78.3 ± 9.2		
Conventional CAD design	15	91.5 ± 10.4	-3.682	0.001

At the axial region, the AI-assisted group showed a mean internal gap of 94.6 ± 11.3 µm, whereas the conventional CAD group showed a mean internal gap of 106.8 ± 12.1 µm. The difference between the groups was statistically significant (p = 0.008).

Table 3. Comparison of axial internal gap between the two groups

Group	n	Mean ± SD (µm)	t-value	p-value
AI-assisted crown design	15	94.6 ± 11.3		
Conventional CAD design	15	106.8 ± 12.1	-2.854	0.008

At the occlusal region, the mean internal gap was 118.2 ± 15.4 µm in the AI-assisted group and 132.5 ± 16.2 µm in the conventional CAD group. The difference was statistically significant (p = 0.020).

Table 4. Comparison of occlusal internal gap between the two groups

Group	n	Mean ± SD (µm)	t-value	p-value
AI-assisted crown design	15	118.2 ± 15.4		
Conventional CAD design	15	132.5 ± 16.2	-2.478	0.020

Overall, the AI-assisted crown-design group demonstrated lower mean gap values at all evaluated sites compared with the conventional CAD group. The lowest mean discrepancy was observed at the marginal region in both groups, while the highest mean internal gap was observed at the occlusal region.

Table 5. Overall comparison of marginal and internal adaptation

Measurement site	AI-assisted design Mean ± SD (µm)	Conventional CAD Mean ± SD (µm)	p-value
Marginal	72.4 ± 8.6	86.7 ± 10.1	<0.001
Cervical	78.3 ± 9.2	91.5 ± 10.4	0.001
Axial	94.6 ± 11.3	106.8 ± 12.1	0.008
Occlusal	118.2 ± 15.4	132.5 ± 16.2	0.020

The results showed that the AI-assisted crown-design group had lower marginal and internal gap values than the conventional CAD group at all evaluated measurement sites. Statistically significant differences were observed for marginal, cervical, axial, and occlusal adaptation measurements, with all p-values below the predetermined significance level of 0.05.

Thus, within the limitations of the present in vitro experimental design, the AI-assisted crown-design group demonstrated significantly different marginal and internal adaptation values compared with the conventional CAD group.

DISCUSSION

The present in vitro study was conducted to evaluate the effect of AI-assisted crown design on the marginal and internal adaptation of CAD/CAM-fabricated crowns. Thirty standardized specimens were evaluated, with 15 crowns designed using an AI-assisted system and 15 crowns designed using conventional CAD software. Marginal adaptation was considered the primary outcome, while internal adaptation was evaluated at the cervical, axial, and occlusal regions. The results demonstrated lower mean gap values in the AI-assisted crown-design group at all evaluated locations when compared with the conventional CAD group.

The marginal adaptation of CAD/CAM crowns is influenced by several factors, including the restorative material, scanning system, digital workflow, crown-design software, manufacturing procedure, and the accuracy of the internal surface of the restoration. Musa et al. evaluated the effects of restorative material, intraoral scanner, and digital workflow on the marginal and internal fit of CAD/CAM all-ceramic crowns and demonstrated that variations in the digital workflow could influence the adaptation of the resulting restoration [6]. In the present study, the same scanning and manufacturing procedures were used for both groups, while the crown-design method was varied. Therefore, the difference observed between the two groups could be considered primarily in relation to the crown-design approach rather than differences in manufacturing procedures.

In the present study, the AI-assisted group demonstrated a mean marginal gap of 72.4 ± 8.6 µm, whereas the conventional CAD group demonstrated a mean marginal gap of 86.7 ± 10.1 µm. The difference was statistically significant. Farah and Alresheedi evaluated the marginal and internal fit of CAD/CAM crowns designed using three different dental CAD programs and demonstrated that the choice of CAD software could influence the adaptation of the fabricated crowns [7]. Their findings support the importance of the digital design stage as one of the factors contributing to the final adaptation of CAD/CAM restorations. The lower marginal gap observed in the AI-assisted group in the present study may therefore be associated with the ability of the AI-based system to generate a standardized digital crown geometry based on the scanned preparation.

Sánchez-Lara et al. evaluated the marginal and internal fit of single crowns fabricated using an analog workflow and different CAD/CAM systems in a prospective clinical study [8]. Their work emphasized that the workflow used for fabrication can influence the fit of single crowns. In the present investigation, a completely standardized digital workflow was used for both groups, with the primary difference being the crown-design method. This standardization was important because it reduced the potential influence of other variables and allowed the effect of AI-assisted crown design to be evaluated more directly.

The internal adaptation findings of the present study showed a progressive increase in gap values from the cervical region toward the occlusal region in both groups. The AI-assisted group showed a mean cervical internal gap of 78.3 ± 9.2 µm, compared with 91.5 ± 10.4 µm in the conventional CAD group. At the axial region, the corresponding values were 94.6 ± 11.3 µm and 106.8 ± 12.1 µm, respectively. At the occlusal region, the mean internal gaps were 118.2 ± 15.4 µm for the AI-assisted group and 132.5 ± 16.2 µm for the conventional CAD group.

The greater occlusal gap observed in comparison with the cervical and axial regions may be related to the complexity of three-dimensional occlusal anatomy and the spatial relationship between the internal surface of the crown and the prepared tooth. Rizonaki et al. evaluated the marginal and internal fit of lithium disilicate CAD/CAM crowns using micro-computed tomography and demonstrated that internal adaptation varied according to the evaluated region of the restoration [9]. Their findings support the importance of evaluating adaptation at multiple standardized locations rather than relying solely on a single measurement of crown fit.

The present findings also need to be considered in relation to the effect of internal adjustment on crown adaptation. Hasanzade et al. investigated how adjustment could affect the internal and marginal adaptation of CAD/CAM crowns fabricated using different restorative materials [10]. Their study demonstrated that internal adjustment can influence the adaptation of CAD/CAM crowns. In the present study, no additional internal adjustment was performed before adaptation measurements. This was done deliberately to evaluate the adaptation produced by the respective digital crown-design methods without introducing an additional operator-dependent variable.

Tabata et al. evaluated the marginal and internal fit of CAD/CAM composite resin and ceramic crowns before and after internal adjustment [11]. Their findings further demonstrated that internal modification of a restoration can alter its marginal and internal fit. The present study differed in that the crowns were evaluated without internal adjustment, thereby allowing the intrinsic effect of the crown-design workflow to be assessed. The lower gap values observed in the AI-assisted group therefore suggest that the AI-generated digital design was able to produce a comparatively close adaptation before any manual internal correction was performed.

The effect of cementation and aging on marginal fit has also been investigated in CAD/CAM crowns. Del Piñal et al. evaluated the marginal fit of veneered and monolithic zirconia and metal-ceramic CAD/CAM crowns following cementation and aging [12]. Their findings demonstrated that the marginal relationship of a crown can be affected by factors occurring after fabrication. In the present study, the crowns were evaluated before cementation and artificial aging. Consequently, the present findings primarily represent the adaptation achieved immediately after digital design and CAD/CAM fabrication and should not be interpreted as a direct representation of long-term clinical marginal behavior.

Huang et al. evaluated the clinical marginal and internal fit of crowns fabricated using different CAD/CAM technologies and demonstrated that the fabrication technology could influence crown adaptation [13]. The present study similarly highlights the importance of digital technology in determining crown fit. However, unlike a comparison between different CAD/CAM manufacturing technologies, the present investigation maintained

the same manufacturing system and varied the crown-design approach. This distinction is important because it suggests that differences in adaptation may occur even when the manufacturing process is kept constant.
Tamac et al. compared the clinical marginal and internal adaptation of crowns produced using CAD/CAM milling, laser sintering, and conventional casting techniques [14]. Their study demonstrated differences in adaptation among different manufacturing approaches. In the present study, the manufacturing technique was standardized across both experimental groups. Therefore, the comparison was focused specifically on the influence of AI-assisted versus conventional digital crown design, rather than on differences between manufacturing technologies.
Lee et al. compared the marginal and internal fit of all-ceramic crowns fabricated using two different CAD/CAM systems and reported that the digital system used for crown fabrication could influence adaptation [15]. These findings, together with the observations from previous studies, indicate that crown adaptation is a multifactorial outcome involving digital scanning, software design, manufacturing technology, restorative material, and post-processing procedures. The present study attempted to control these variables by using standardized tooth preparations, the same scanning procedure, the same restorative material, the same CAD/CAM manufacturing system, and the same measurement protocol for both groups.
The results of the present study demonstrated statistically significant differences in marginal, cervical, axial, and occlusal adaptation between AI-assisted and conventional CAD-designed crowns. The consistently lower gap values observed in the AI-assisted group suggest that the AI-assisted design approach may provide a more consistent internal geometry and marginal relationship under the conditions evaluated in this in vitro experiment. However, these findings should be interpreted within the limitations of the experimental design.
The use of standardized artificial tooth preparations provided good control over specimen geometry and reduced biological variability, but it did not reproduce all the characteristics of natural teeth. In addition, the study evaluated crowns before cementation and artificial aging, and therefore the influence of thermal cycling, mechanical loading, cementation, and long-term intraoral conditions was not assessed. Furthermore, the results were obtained using a specific AI-assisted design system, CAD software, scanning protocol, restorative material, and manufacturing system. Consequently, the findings cannot automatically be generalized to all AI-based crown-design systems or all CAD/CAM workflows.
Within the limitations of the present in vitro study, AI-assisted crown design demonstrated lower marginal and internal gap values than conventional CAD crown design at the evaluated measurement sites. The findings suggest that the crown-design stage may represent an important factor influencing the adaptation of digitally fabricated crowns. Further investigations involving larger sample sizes, different AI systems, different restorative materials, natural teeth, cementation procedures, and long-term aging conditions would be required to determine the clinical significance and reproducibility of these findings.

CONCLUSION

Within the limitations of the present in vitro study, AI-assisted crown design demonstrated lower marginal and internal gap values compared with conventional CAD-based crown design.
The AI-assisted crown-design group showed a lower mean marginal gap as well as lower internal gap values at the cervical, axial, and occlusal regions. The differences between the two crown-design approaches were statistically significant at all evaluated measurement sites.
The findings indicated that the method of digital crown design influenced the marginal and internal adaptation of CAD/CAM-fabricated crowns. AI-assisted crown design showed favorable adaptation under the standardized experimental conditions used in the present study.
Therefore, AI-assisted crown design may represent a promising approach for improving the consistency and accuracy of digitally designed dental crowns. However, further studies involving natural teeth, different restorative materials and AI systems, cementation, artificial aging, and clinical conditions are required to establish the long-term clinical relevance of these findings.

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