



Fit accuracy of complete crowns fabricated by generative artificial intelligence design: a comparative clinical study

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PURPOSE. Designing restorations remains challenging because the process is time-consuming and requires operator skill and experience. This clinical study evaluated the fit accuracy of polymerized complete crowns fabricated using a web-based 3D generative artificial intelligence design (GAID) method compared to crowns fabricated using a conventional computer-aided design (CCAD) method.

MATERIALS AND METHODS. Sixty-two patients requiring complete crowns in maxillary and mandibular premolars and molars were enrolled. After tooth preparation, digital impressions were taken using an intraoral scanner. Two crowns per patient were designed: one used a web-based automatic 3D GAID software program, and the other used a standard human-driven CCAD software program. The crowns were 3D-printed and delivered to the patients. Marginal and internal discrepancies and occlusal contacts were evaluated using a digital triple scan technique. Statistical analysis used two one-sided t-tests for paired samples to assess crown accuracy in both methods ($\alpha = .05$). **RESULTS.** Marginal gaps of crowns made by both methods showed equivalence in the buccal, mesial, and distal regions; however, in the lingual region, the GAID method produced higher marginal discrepancies ($P > .001$). Regarding internal gaps, no significant difference was observed between the two methods. Crowns produced by the GAID method exhibited larger occlusal discrepancies than those made by the CCAD method ($P < .001$). **CONCLUSION.** The fit accuracy of crowns fabricated using generative artificial intelligence was equivalent to those produced using the manual-input computer design method when the margins were well defined. While marginal and occlusal discrepancies were within clinically acceptable range, careful attention must be given to automated design outcomes, considering various tooth preparation shapes, anatomical structures, and clinical variations. [J Adv Prosthodont 2025;17:224-34]

KEYWORDS

Accuracy; Artificial intelligence; Complete crown; Design; Fit

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INTRODUCTION

Anatomic crown restorations are critical in prosthodontic treatment for cases involving extensive carious lesions, cracked teeth, and endodontically treated teeth at risk of fracture.¹ The advancement of modern dental technology has led to increasing patient demand for precise treatments. Interim restorations are used in the intermediate phase of fixed prosthodontic treatment procedures, particularly for esthetic restorations. These interim restorations serve multiple crucial functions, including previewing definitive crowns,² protecting vital tissues of prepared teeth and surrounding periodontium, maintaining the position of prepared teeth to prevent unwanted movement during long interval treatment times, and preserving oral function and esthetics before the delivery of definitive restorations.^{3,4}

As digital technology is increasingly integrated into daily dental practice, interim crowns can be routinely prepared using computer-aided design and computer-aided manufacturing (CAD-CAM).⁵ CAD-CAM systems are available in primary configurations, including centralized manufacturing centers, dental laboratories, and chairside units.⁶ Recently, chairside CAD-CAM systems have offered a streamlined approach, enabling crown fabrication and delivery in a single visit through a complete digital workflow. This comprehensive procedure involves three main steps, including the acquisition of 3D scan data of prepared teeth, designing crowns using a CAD software program, and manufacturing the prostheses using the subtractive/additive method.⁷ This chairside approach not only enhances efficiency but also improves patient experience by reducing the number of visits.⁸

CAD software for designing crown restorations plays an important role in achieving accurate and esthetically pleasing results. Traditional CAD software has long been the standard and requires dental professionals to manually design each aspect of the crown.⁹ Although effective, this process is time-consuming and highly dependent on operator skill and experience. The integration of artificial intelligence (AI) into dental CAD systems allows the calculation of the 3D geometric relationship between prepared

teeth and surrounding dentition, facilitating the design of patient-specific crowns.¹⁰ In this setting, neural networks, a form of adaptable machine learning, are used to generate biometric crown designs. The AI system is trained using digitally designed data and the morphology of the remaining dentition as input, with neural networks specifically designed for detection, segmentation, and generation.^{11,12} The recent introduction of AI-based CAD software equipped with advanced deep learning algorithms, such as convolutional neural networks (CNN) and generative adversarial networks (GAN), offers the generation of precise and realistic crown designs.¹³ CNN is designed for image reorganization, segmentation, and classification to interpret detailed dental images. Meanwhile, GAN can generate realistic dental images that resemble natural teeth, optimizing crown fit, alignment, and esthetics.¹³ These novel approaches use advanced generative AI technology to automatically create 3D crown designs based on patient anatomical data and established dental principles.¹⁴

AI-based CAD software offers several advantages over traditional methods, including significantly reduced design time, greater consistency of results by reducing human dependency, and the ability to learn and improve from previous designs.¹⁵ Furthermore, AI-based CAD software can simultaneously consider several variables, producing an ideal design that balances esthetics and functionality.¹⁶⁻¹⁸ While human control remains important, integrating AI into crown design has revolutionized digital dentistry and improved the efficiency and quality of prosthetic treatment.

Given that the AI-based automated CAD software is newly developed, it is essential to evaluate the reliability of the new method in clinical settings. The purpose of this study was to assess the fit accuracy of interim crowns designed using a web-based generative AI design (GAID) method, compared to those designed using the well-established conventional CAD (CCAD) method in clinical treatment. The null hypothesis posits no significant difference in fit accuracy and occlusal contact between crowns generated by the automated GAID method and the human-driven CCAD method.

MATERIALS AND METHODS

The study workflow is illustrated in Figure 1. Patients who required single complete crowns in the posterior teeth were consecutively enrolled. The sample size for this study was determined using power analysis in G*Power software (version 3.1.9.7; Heinrich Heine University, Düsseldorf, Germany). The means and standard deviations from a preliminary paired-sample test (Method A: $70 \pm 29 \mu\text{m}$; Method B: $60 \pm 24 \mu\text{m}$) were entered for a two one-sided t-tests analysis for paired samples (standardized mean difference), resulting in a calculated effect size of 0.372. With a significance level of 0.05 and a power of 0.80, the analysis indicated that 59 participants were required. The inclusion criteria comprised both vital teeth and endodontically treated teeth that required complete crown restorations. Eligible teeth included those with restorable morphology, restorable fractures, or exten-

sive carious lesions confined to the supragingival level, in accordance with the supragingival preparation concept. Additional inclusion criteria were a healthy periodontal status and satisfactory oral hygiene. The exclusion criteria included endodontically treated teeth that had undergone hemisection, teeth with non-restorable fractures or carious lesions extending beyond the cemento-enamel junction, the presence of uncontrolled periodontal disease, symptomatic teeth, and poor oral hygiene. This study followed the Reporting of Noninferiority and Equivalence Randomized Trials (Extension of the CONSORT 2010),¹⁹ and received approval from the institutional review board of Kyungpook National University Dental Hospital (Approval number: KNUDH-2024-04-04-00 and 2020-12-02-00). Written informed consent was obtained from all patients before the study. The clinical trial was listed in the Clinical Research Information Service (CRIS) maintained by the Korea Disease Control

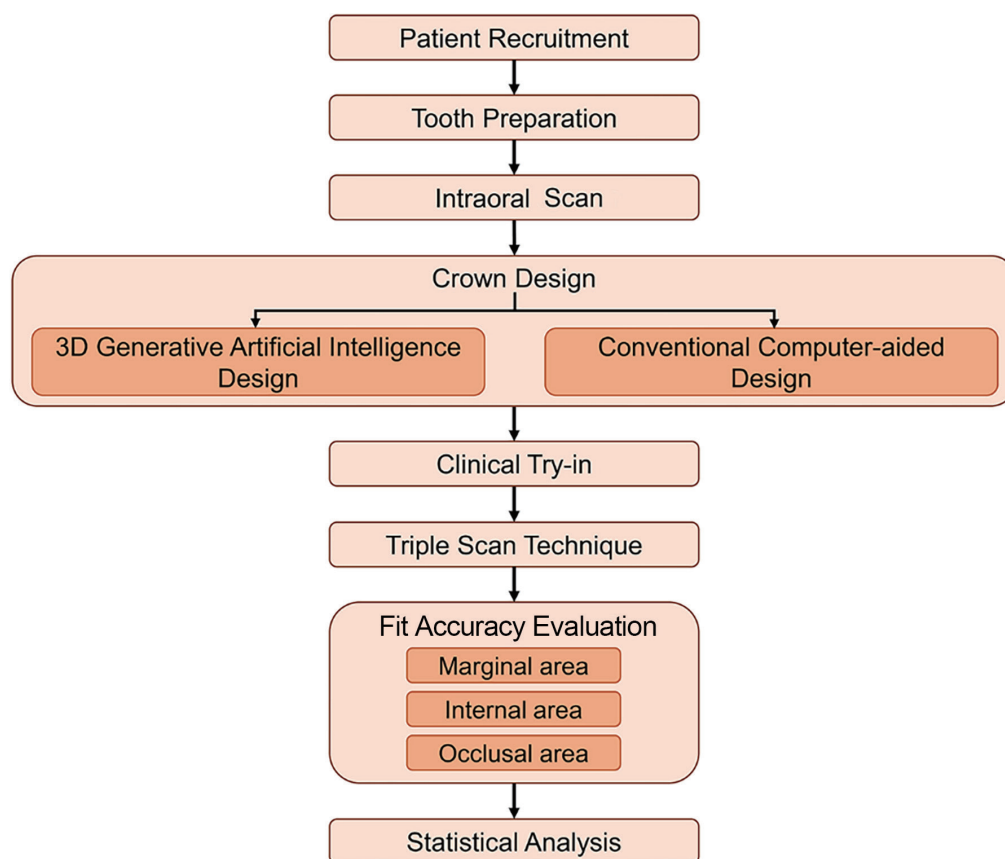


Fig. 1. Study design.

and Prevention Agency (KDCA) (registration number: KCT0008795).

Tooth preparations for single complete crowns in the premolar and molars were performed with the supragingival margin concept by an experienced clinician. The preparation protocol involved an occlusal reduction of 1.5 mm, axial reduction of 1.0 mm, and the establishment of a 1.0 mm-wide deep chamfer finish line on the buccal surface, with chamfer margins on the proximal and lingual surfaces. Digital impressions were taken using a structured light based intraoral optical scanner (i700; Medit, Seoul, Korea). The scanner moved over the occlusal, buccal, and lingual surfaces of teeth straight first, and then cross-sectional movement (rolling motion) was followed for the proximal areas. Digitized dental models were exported in polygon file format (PLY) and utilized for crown design. Each patient received two crown designs in the same prepared tooth: one with a web-based automated 3D GAID software program (Dentbird Crown version V.3.X.X; Imagoworks, Seoul, Korea) and the other with a standard human-driven CCAD software program (DentalCAD 3.0 Galway; ExoCAD, Darmstadt, Germany) by a dental technician with more than 10-year CAD experience. In the GAID

method, the registration of tooth preparation finish line and the designing of crown contour were provided by the software automatically; whereas, in the CCAD method, the technician performed both procedures manually. The design parameters for both software programs were 60 μ m of cementation space, 0.8 mm of no cementation space above the finish line, 0.2 mm in bottom thickness, 45° of bottom angle, and -0.02 mm distance to adjacent teeth. Figure 2 illustrates the comparison of the two CAD workflows.

The designed crowns were converted to polymeric restorations using a digital light processing (DLP) 3D printer (Asiga UV Max; Asiga, Sydney, Australia) with a 3D printing photopolymer material (C&B 5.0 Hybrid; Arum Dentistry). The layering thickness of 3D printing was 50 μ m and the wavelength of curing light was 405 nm. The printing orientation was set at 45°, resulting in the support structures being primarily located on the occlusal and lingual surfaces, away from the crown margins (Fig. 3). After printing, the resin base and supporting structures were removed with minimal force to avoid unnecessary deformity. The interim crowns underwent thorough cleaning in an alcohol solution using an ultrasonic cleaner (Elma-sonic S30; Elma Schmidbauer, Singen, Germany) for

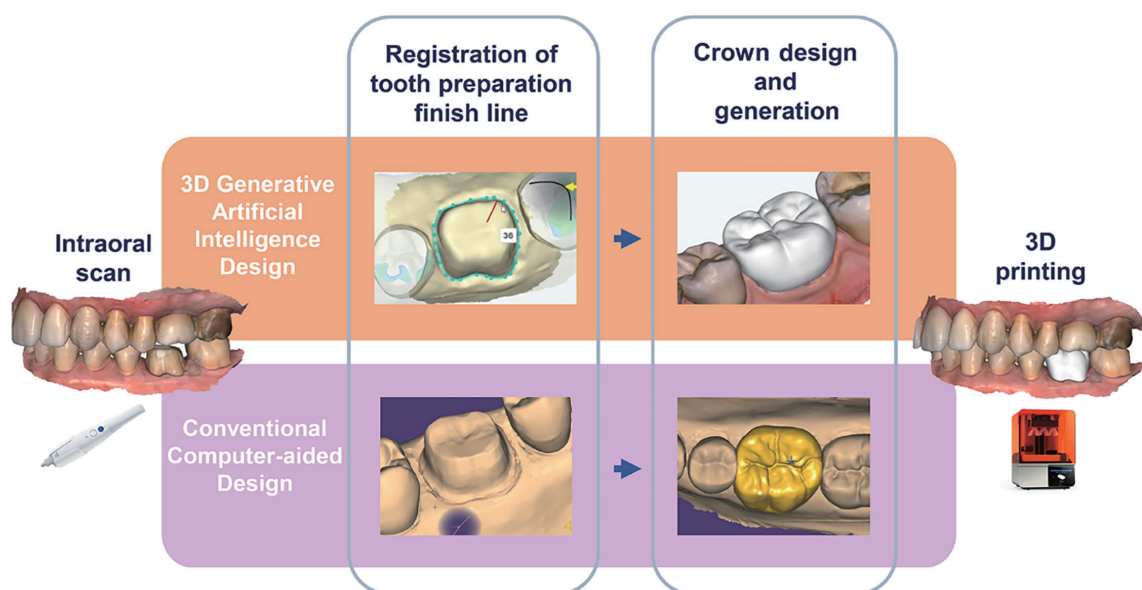


Fig. 2. Workflow of crown fabrication using automated generative artificial intelligence design and conventional computer-aided design methods.

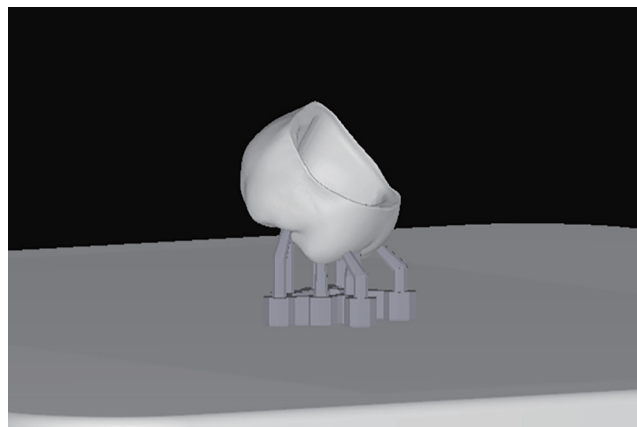


Fig. 3. Printing orientation set at 45° with support structures.

3 min to remove any resin residue. Following this, the post-curing process was used for 10 min to complete polymerization (ARUM UV Curing Machine; Arum Dentistry, Daejeon, Korea). Additional finish and polishing procedures for the crowns were not conducted to preserve the crown morphology.

The printed crowns were seated on the prepared teeth in the oral cavity using finger pressure. The proximal surfaces were adjusted when the tightness of the proximal contacts hindered the full seating of the crowns. The 3D scans of the crown-tooth assemblies were obtained under pre-cementation conditions to enable a direct comparison between the crowns generated by two different software systems. The clinical adaptations of crowns in the GAID and CCAD methods were evaluated using a triple scan technique (Fig. 4).^{20,21} Accordingly, 3D scans of printed crowns, prepared teeth, and their assembly in the oral cavity were obtained and aligned for assessment using a 3D analysis software program (Geomagic Design X version 2019.0.0; 3D Systems, Rock Hill, SC, USA). The 3D scans of the printed crowns were obtained by digitizing them using the structured light-based intraoral scanner and dedicated software (Meditlink version 3.3.1; Medit, Seoul, Korea). For the scanning procedure, the scan began over the occlusal surface, then proceeded to the buccal, lingual, mesial, and distal regions using cross-sectional movements that followed the tooth curvature. The intaglio surfaces of the crowns were subsequently scanned by rotating the scanner head from the outer surface toward the

internal surface. In this alignment process, scans of prepared teeth in the maximum intercuspation model served as the reference, with adjacent teeth used as matching areas to align the assembly images. After completing the alignment, digitized images of crowns were aligned on the assembly images and used to measure the fit accuracy of crowns.

The trueness of crown fabrication was evaluated at marginal, internal, and occlusal regions. Absolute marginal discrepancy was defined as the distance from the most external points of the crown margin to the external finish line of tooth preparation, measured at the mid-plane of buccal, lingual, mesial, and distal regions. Internal discrepancy was defined as the distance between the intaglio surfaces of crowns and prepared teeth, and was measured at the mid-plane of buccal, lingual, mesial, distal, and occlusal regions in both buccolingual and mesiodistal sectioning planes. Occlusal contacts were assessed by measuring the distance between the functional cusp tips of crowns and antagonist teeth in the bite registration position. The definitions of gap measurement are illustrated in Figure 5. The investigator performing the measurements (J.-E.K.) was blinded to the allocation group to minimize bias.

The data collected in this clinical trial were calculated as the mean $\pm$ standard deviation for absolute marginal discrepancies, internal gaps, and occlusal contacts. The results of the Kolmogorov-Smirnov test indicated a normal distribution of the data ($P = .38$). To investigate the equivalence of the two study methods, GAID and CCAD, in terms of fit accuracy at the assessment points, two one-sided paired t-tests were used. The mean difference in fit and the 90% two-sided confidence interval (CI) between the two methods were calculated using paired t-tests. Equivalence was established if the entire CI fell within a predefined equivalence margin of $\pm 15 \mu\text{m}$.²² The power of the test was set at 80%. All statistical analyses were performed using RStudio (version 0.96.932; Posit, Boston, MA, USA).

RESULTS

Sixty-two patients requiring single complete crowns on maxillary or mandibular premolars and molars

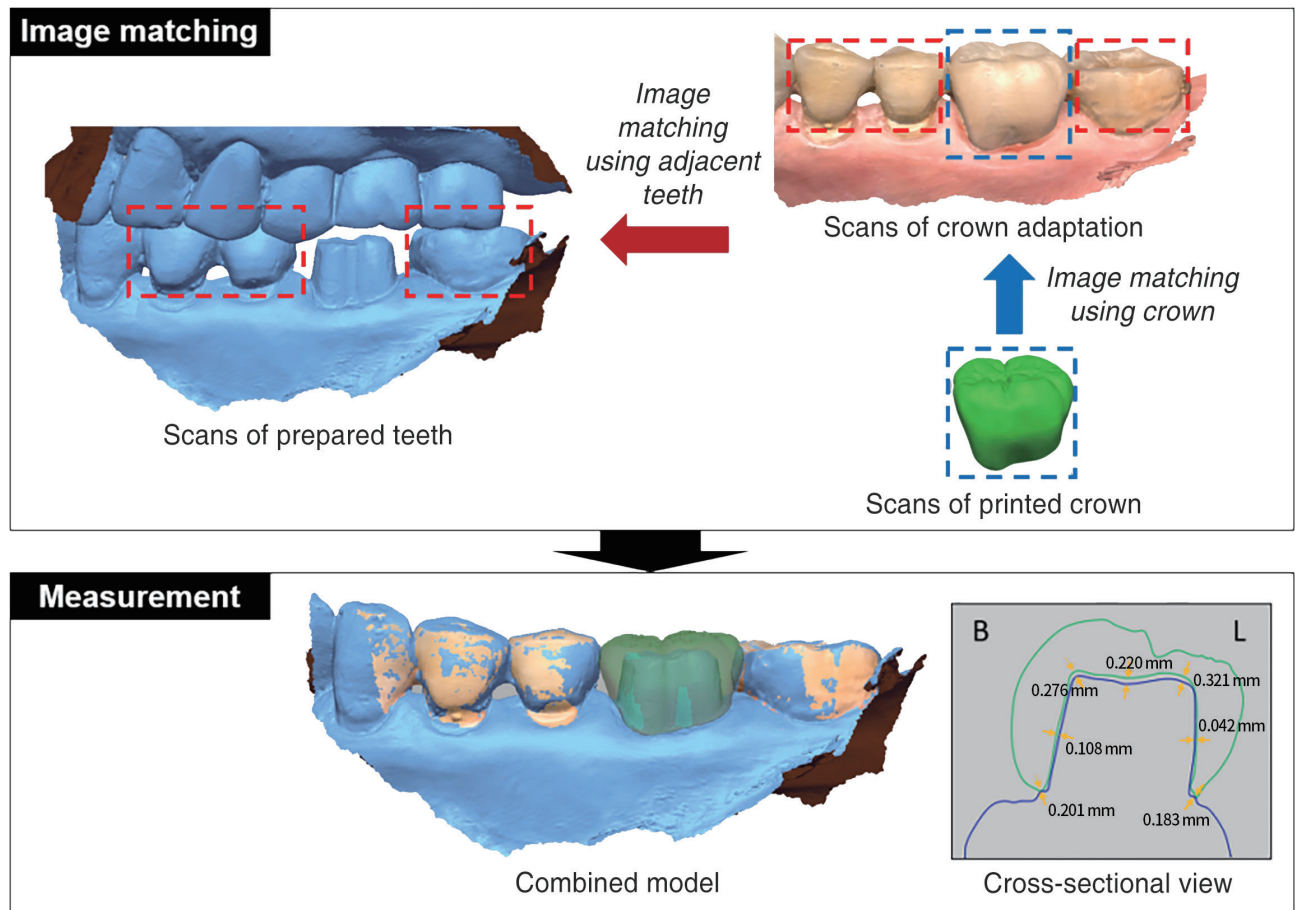


Fig. 4. Aligned image with 3D scans of printed crowns, prepared teeth, and their assembly using the triple scan technique.

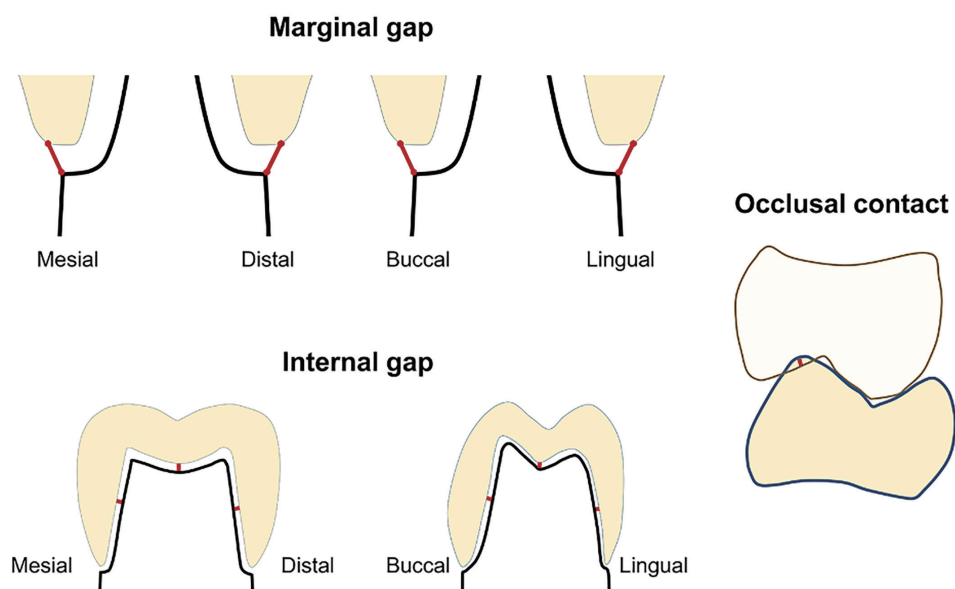


Fig. 5. Measurement points at marginal, internal, and occlusion areas.

were enrolled. Participant and tooth information are presented in Table 1. Table 2 and Figure 6 show the marginal discrepancies, internal gaps, and occlusal contacts of interim crowns designed using the GAID and CCAD methods. The equivalence analysis (Fig. 7) for marginal discrepancies revealed a mean difference of $-2.8 \mu\text{m}$ (90% CI: 1.6 to 4.1) at the buccal region. At the mesial region, the difference was $-1.16 \mu\text{m}$ (95% CI: -4.8 to 2.5), and at the distal region, $2.0 \mu\text{m}$ (95% CI: -1.3 to 5.2). The two-sided 90% CIs for fit accuracy in these regions fell within the predefined equivalence margin of $\pm 15 \mu\text{m}$ ($P < .001$). Meanwhile, the lingual marginal discrepancy showed a mean difference of $10.7 \mu\text{m}$ (90% CI: 6.4 to 15.0), which exceeded the predefined margin, indicating that equivalence was not established at the lingual margin ($P = .051$).

Table 1. Participant characteristics

Characteristics		Values
Sex	Men	28 (45.2%)
	Women	34 (54.8%)
Age (years)		57.2 ± 13.6
Tooth location	Maxilla, Premolar	12 (19.4%)
	Maxilla, Molar	16 (25.8%)
	Mandible, Premolar	7 (11.3%)
	Mandible, Molar	27 (43.5%)

Regarding internal adaptation, the mean internal gap at each surface ranged from $82 \mu\text{m}$ to $98 \mu\text{m}$. The standard deviation of internal gap measurements at the buccal surface was higher than those at the other surfaces. Equivalence analysis revealed mean differences of $-5.6 \mu\text{m}$ (90% CI: -13.8 to 2.7; $P = .031$) at the buccal gap, $-1.3 \mu\text{m}$ (90% CI: -2.5 to -0.2 ; $P < .001$) at the lingual gap, $2.1 \mu\text{m}$ (90% CI: 0.8 to 3.5; $P < .001$) at the mesial gap, $2.7 \mu\text{m}$ (90% CI: -2.3 to 7.7; $P < .001$) at the distal gap, and $3.1 \mu\text{m}$ (90% CI: -0.8 to 7.0; $P < .001$) at the occlusal gap. Based on the predefined equivalence margins, these findings indicate that the differences between the two methods fell within the equivalence region for internal gaps in all directions.

As to occlusal contact, crowns designed using the GAID method exhibited larger discrepancies ($149 \pm 66 \mu\text{m}$) compared to those fabricated with the CCAD method ($105 \pm 63 \mu\text{m}$). The difference in mean discrepancy values was $43.9 \mu\text{m}$ (90% CI: 38.6 to 49.4), which did not fall within the equivalence margin, suggesting that equivalence was not established in occlusal contact ($P = 1.000$).

DISCUSSION

This study aimed to evaluate the fit accuracy of complete crowns designed using generative AI-based design software and compared it to the fit accuracy of

Table 2. Mean and standard deviation of measurement values for fit accuracy of interim crowns designed using generative artificial intelligence design and conventional computer-aided design methods (μm)

		Generative artificial intelligence design	Conventional computer-aided design	P-value*
Marginal discrepancy	Buccal	69 ± 48	67 ± 49	$< .001$
	Lingual	60 ± 32	50 ± 31	.051
	Mesial	46 ± 30	47 ± 28	$< .001$
	Distal	65 ± 43	63 ± 43	$< .001$
Internal discrepancy	Buccal	90 ± 100	95 ± 84	.031
	Lingual	97 ± 79	98 ± 81	$< .001$
	Mesial	89 ± 54	87 ± 55	$< .001$
	Distal	85 ± 57	82 ± 51	$< .001$
	Occlusal	91 ± 61	88 ± 63	$< .001$
Occlusal discrepancy	Contact	149 ± 66	105 ± 63	1.00

*Equivalence testing with using two one-sided paired t-tests.

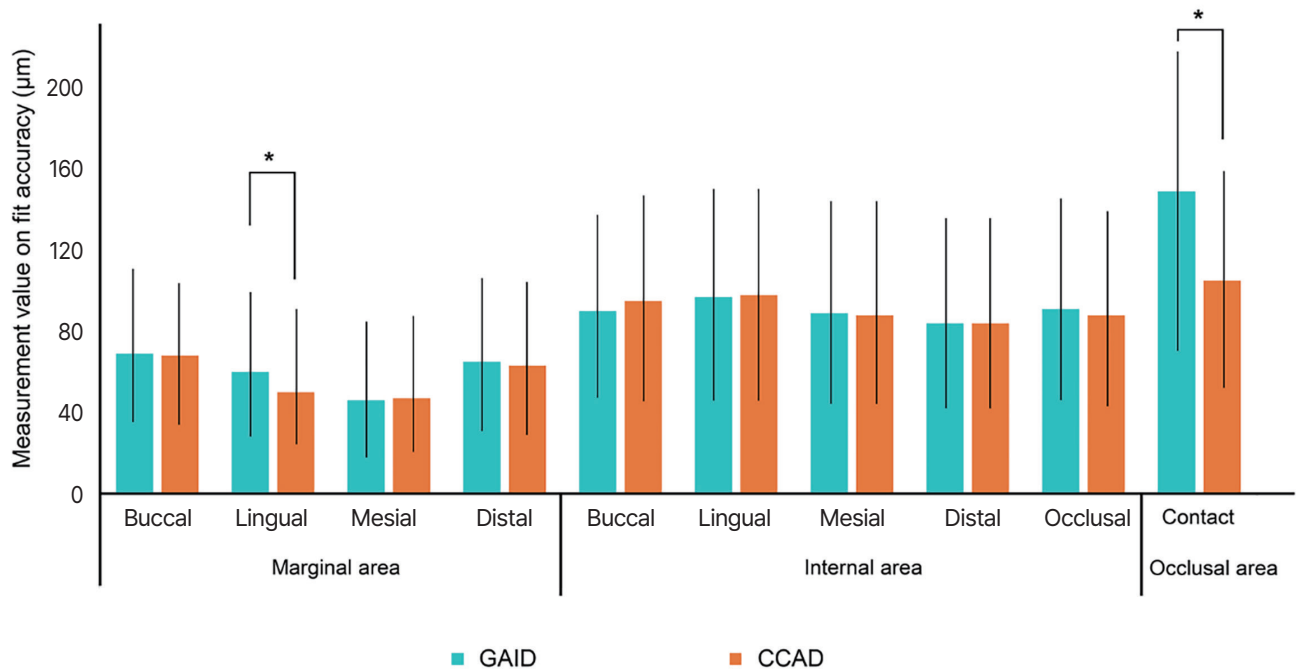


Fig. 6. Marginal discrepancy, internal gap, and occlusal contact of interim crowns designed using generative artificial intelligence design (GAID) and conventional computer-aided design (CCAD) methods. *Significant difference.

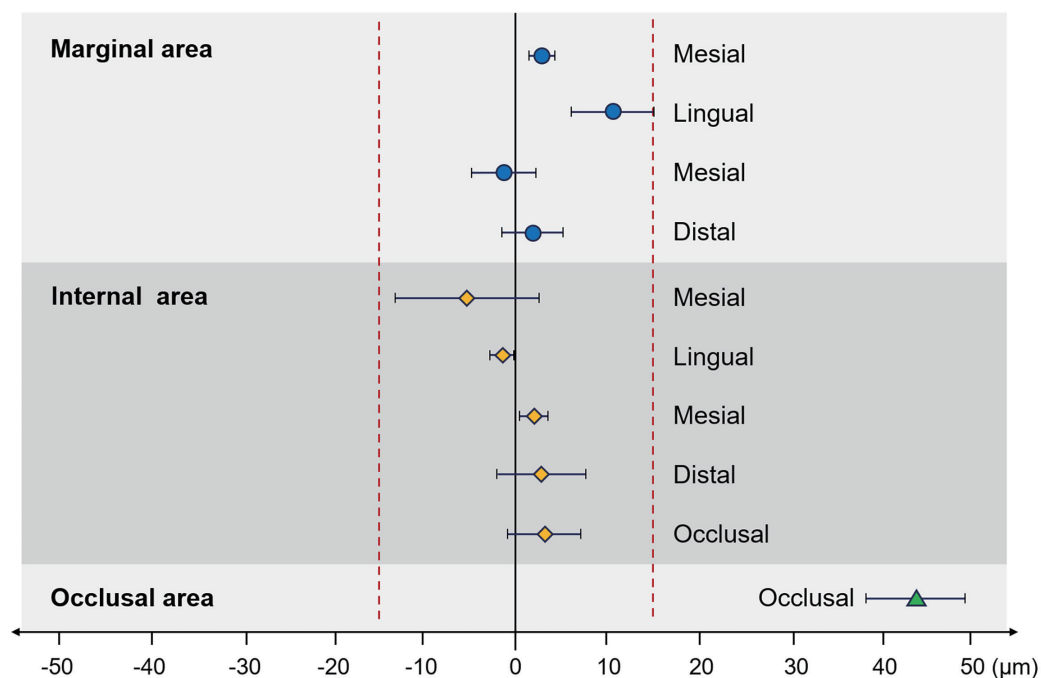


Fig. 7. Equivalence plot displaying the mean differences in marginal, internal, and occlusal areas between paired using generative artificial intelligence design (GAID) and conventional computer-aided design (CCAD) method. Horizontal bars indicate two-sided 90% confidence interval (CI) of the fit difference between groups. The zone between the dashed lines indicates the equivalence limit margin.

crowns designed with human-driven manual CAD software in a clinical setting. The results showed that the GAID and CCAD methods produced equivalent outcomes in marginal discrepancies on the buccal, mesial, and distal sides, as well as in internal gaps across all surfaces; Meanwhile, statistically significant differences were observed in the lingual margin and occlusal contacts in the pairwise comparisons. Thus, the null hypothesis of this study, which posited no differences in the fit accuracy and occlusal contact of interim crowns designed by the GAID and CCAD methods, was partially rejected.

Complete crowns generated by the GAID method demonstrated marginal adaptation within a clinically acceptable range of 100 μm and showed accuracy levels comparable to those achieved by the CCAD method. This finding suggests that GAID can automatically design dental prostheses with high accuracy.²³ The result aligns with the previous study on the internal fit of dental crowns, which found no significant difference between deep learning-based and technician-based dental software.²⁴ The CNN-based GAID method facilitates the identification of the abutment tooth number through the preparation-tooth-extractor module, generates the intaglio surface, creates a parametric surface, performs undercut block-out, and applies multivariable offset through the inner-surface-generator module.^{13,25} This technological advancement is particularly significant as it provides a promising alternative to conventional CAD methods, offering an effective yet reliable approach to dental prosthesis design. Leveraging GAID can significantly reduce human effort, potentially streamlining the completely digitalized manufacturing process.²⁶ Continuous advancement in GAID technology holds promise for further refining its capabilities and expanding applications in dental fixed and removable prostheses.

The margin-line-segment module applied in GAID technology creates a set of points representing the 3D margin lines of prepared teeth. These 3D margin lines undergo several computational conversions to segment the prepared and surrounding tissue areas; the human-driven CCAD method relies on variation in color or texture of the area to identify the potential finish line.^{13,27} In this study, the marginal discrepancy

values for crowns were similar between methods on the buccal, mesial, and distal sides. Meanwhile, the marginal discrepancy was higher in the GAID method at the lingual preparation margin. This difference can be attributed to the fact that crowns designed using the GAID method rely solely on automated functions; however, the CCAD method involves human decision-making, guiding the registration of tooth preparation finish line. The disparities were notably evident in lingual and distal margins, where the finish line configuration can be less distinct in clinical situations. The finishing line on those areas often appears as a feather edge due to challenges in visibility and operation during tooth preparation.²⁸ A previous study mentioned that the algorithms accurately detected most points around the true finish line when the scan was conducted in the stone cast, resulting in a well-defined margin line.¹³ Therefore, another possible reason could be the distortion of the finish line shape in intraoral scan images, stemming from challenges in accurately capturing the interproximal areas of prepared teeth, especially in the posterior region.²⁹ This could be another reason of more discrepancy on the distal and lingual sides. The missing scan area might be altered by the automated repair function of computer software, potentially resulting in errors in reconstructed tooth preparation models.³⁰ Automatic detection of these unclear or faulty margins becomes difficult, potentially leading to inaccuracies in margin registration.²⁸ Therefore, the absence of post-adjustment for automatically detected marginal lines in the GAID method might lead to higher marginal discrepancies than the CCAD method, emphasizing the importance of precise margin registration in dental CAD software and the need for advancements in AI-based automated finishing line registration technologies on challenging surfaces, particularly the lingual and distal surfaces of prepared teeth.

Regarding occlusal contact evaluation, the crowns automatically generated by the GAID method exhibited higher discrepancies than those designed by CCAD, probably due to the inherent software settings and mathematical algorithms of AI in software programs. Consistent with this finding, a previous study found numerous premature occlusal contacts in AI CAD-driven software compared to crowns designed

by conventional CAD software.²⁴ In clinics, premature occlusal contacts can be eliminated by occlusal adjustment in a subtractive way. However, infraoccluded crowns necessitate more time and extensive procedures with added material compatibility concerns. Because of the clinical factors, the automated design software was set so that occlusion can be in good contact. Occlusal morphology could be another possible reason for the occlusal discrepancy. GAID tended to produce more generalized anatomical structures on occlusal surface.³¹ On the other hand, crowns designed in conventional dental CAD software by experienced dental technicians often feature detailed and meticulously adjusted occlusal structures to adapt to the patient's more specific occlusion condition. This finding raises awareness regarding the reliance on AI automated generation functions in designing the occlusal surface of prostheses. Meticulous checking and adjustment of occlusal surfaces may be necessary in the design process, particularly in patients with malocclusion or those who have undergone orthodontic treatment.

A limitation of this study was the lack of evaluation of user experience. The benefits of AI applications include improved workflow efficiency and user-friendliness. A user-centered study should be conducted in the future to gain a more comprehensive understanding of the impact of AI applications on user satisfaction and convenience in operating design software, as well as to suggest improvements in automation functions. In addition, demographic characteristics and tooth location were not considered as variables. These factors should be included in future studies to assess their potential influence on the outcome measures. Lastly, the evaluation of proximal contacts in crowns should also be addressed in future research, ideally encompassing a broader range of clinical conditions to more thoroughly investigate clinical implications.

CONCLUSION

This fit accuracy of complete crowns designed by generative AI was within a clinically acceptable range and equivalent to those designed by conventional CAD software when the margins were well defined.

However, when relying on automatic functions for registering margins and occlusal surfaces of dental crowns, caution should be taken in the inherent setting of the software algorithm and inspecting the resulting design in the indistinct finish line of tooth preparation.

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