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Comparative Evaluation of the Internal and Marginal Fit of Dental Crowns Designed Using Cad and Ai-Based Software

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KEYWORDS

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ABSTRACT:

Introduction: Zirconia crowns are becoming increasingly popular in dentistry, primarily because they offer exceptional strength, an appealing appearance, and good biocompatibility. While traditional CAD software helps with crown design, it often requires a great deal of manual tweaking. Recently, artificial intelligence (AI) has emerged as a game-changer in this field, providing automated design capabilities that promise to enhance precision and minimize the need for human input.

Aim: This study set out to compare the fit of zirconia crowns designed using AI-based software (Dentbird) with those created using conventional CAD software (Exocad).

Materials and Methods: We included ten patients who needed single crowns for their lower molars. Digital impressions were taken, and crowns were designed using both AI and traditional CAD systems. To evaluate the fit, we used a triple-scan protocol and analyzed the results with Geomagic Control X. We performed statistical analysis using SPSS version 21.

Results: The crowns designed with AI software showed a noticeably better fit, both internally and at the margins, compared to those made with conventional CAD software. This improvement was particularly significant in the buccal and distal regions ($p < 0.005$).

Conclusion: The findings highlight that AI-based crown design software outperformed traditional CAD methods in achieving a better fit. This suggests that AI could significantly enhance clinical accuracy and make digital workflows in prosthodontics more efficient.

INTRODUCTION

Zirconia restorations are indeed a popular treatment option that is found in modern dentistry since they are biocompatible, strong, and aesthetic. CAD technology involves the conventional method in fabricating zirconia crowns. CAD software improves precision, yet dentists and technicians still design and refine complex restorations because CAD systems lack medical robotics' adaptive capabilities, often requiring manual post-processing as well as intraoral adjustments. These technologies have improved efficiency of the fabrication stage in a large way as a result of that. Thereby, the overall optimization of the workflow is limited by reliance on human intervention that continues for design modifications and clinical fine-tuning.[1,2]

In recent years, artificial intelligence (AI) has become an integral part of the medical field because it expands into areas such as education, healthcare, as well as digital imaging. Algorithms programmed in AI use big data plus internet models for task assistance. Digital technology advancements make it possible.[3] AI within dentistry has emerged as something of a valuable tool through using wide-ranging digital databases for the addressing of complexities for designing dental restorations. Its use for clinical dentistry is gradually increasing, and this increase contributes to diagnostic procedures and prosthetic designing. AI technology operates in a like manner to CAD systems and this operation enables design for restorations like inlays, crowns, and bridges.[2]

The long-term success of dental crowns is influenced by various factors, with marginal adaptation being a critical

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determinant of clinical outcomes. Marginal gap is defined as the vertical distance between the cervical margin of the restoration and finish line of the preparation, which can be assessed using a stereomicroscope under high magnification. Poor marginal adaptation may lead to plaque accumulation, microleakage, recurrent caries, and periodontal disease. A marginal gap of 50 to 120 µm is clinically accepted. Furthermore, the internal fit of a crown is essential for its longevity, as compromised internal adaptation can reduce retention, affect its rotational stability, and lower fracture resistance.[4]

The evaluation of AI-assisted crown design software has mainly focused on design accuracy and efficiency, with less attention given to overall performance assessment. More research is needed to integrate these aspects into comprehensive evaluations. Therefore, this study aimed to assess the performance of AI-powered crown design software program in comparison to conventional CAD software.

METHODOLOGY

This prospective in vivo study was carried out in department of prosthodontics and crown & bridge of Dr. R.R.K dental college and hospital, Akola. Ethical clearance was obtained from the Institutional Review Board and informed consent was secured from all participants.

Adults requiring a single posterior crown were deemed eligible for this study. Ten patients, regardless of gender, requiring single crowns for mandibular first molars were selected for this in vivo study. The indications for restoration included the presence of a deficient existing crown, significant loss of tooth structure, an increased risk of fracture following endodontic treatment, or the occurrence of cuspal fracture. Individuals with severe manifestations of parafunction or probing depths greater than 5 mm, as well as noncompliant participants, were excluded from the study, the patients were asked to sign a written informed consent form for participation in this study, which was approved by the Research Ethics Committee. A preliminary sample size calculation was conducted, with a significance level set at 0.05 and a power of 0.8. This calculation determined that a minimum sample size of 10 participants was necessary.

Teeth were prepared with an equigingival chamfer finish line for full-coverage zirconia crowns with 1 mm of reduction in all surfaces by a single expert prosthodontist. The teeth were cleaned, and the shade of the crowns was determined using a Vita classical shade guide (Vita Zahnfabrik, Bad Säckingen, Germany). Digital impressions were recorded using Trios IOS (3Shape, Copenhagen, Denmark) to obtain STL 1. Temporary crowns were directly fabricated using a self-curing composite resin material (Luxatemp, DMG GMbH, Hamburg, Germany) and cemented using eugenol-free temporary cement (TempoCem NE, DMG GMbH, Hamburg, Germany). [5]

The STL files were fed to the two softwares under study viz. Exocad and Dentbird (Fig. 2C and Fig. 3A)

As Dentbird is an AI based design software, margins of the preparation were automatically detected and the crown were created, modifications were made for minimal changes, and the design was completed and exported. For designing the crowns, the cement space was considered to be 15 µm at the margins and 60 µm in the axial walls and occlusal surface according to the standard recommendations. In the proximal surfaces, the distance to the adjacent teeth was set at zero, and in the occlusal surface, a 10-µm distance was considered from the occlusal surface of the opposing teeth. CAD Crowns were designed using Exocad 3.0 software, following similar parameters.[6]

The final STL files was sent to the milling machine (UP3D P52; UP3D Shenzhen, China). UPCERA ST zirconia blank (Upcera ST, Upcera Dental Technology Co., Ltd., China) was used to mill the crowns. Crowns were then sintered in a zirconia sintering furnace. After completion of sintering, the crowns were stained and glazed at 830 ºC.[5,]

In the second appointment, the temporary crown was removed, and a zirconia crown was placed after thorough cleansing of the prepared teeth for assessment. Initially, a qualitative evaluation of the proximal contacts was performed in accordance with the CDA criteria. The quality of the proximal contact was documented, and adjustments were made using a zirconia diamond bur (Komet; Rock Hill, SC, USA) as needed. Once it was verified that the proximal contacts did not impede the complete seating of the crowns, the internal adaptation of

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the crowns was assessed utilizing a triple scan protocol.[5,6]

The CAD crown and AI crown were initially attached to a reference structure designed to enlarge the specimen and improve scanning precision, after which the assembly was scanned extraorally and labeled as STL 2C and STL 2A (Fig. 4). Subsequently, both crowns, along with the reference structure, were placed on the prepared tooth, and a second scan - referred to as STL 3C and STL 3A (Fig. 5).[7]

All three scans were superimposed using Geomagic Control X software (Fig. 6). To evaluate the internal fit, five points were marked on the mesial, distal, buccal, lingual, and occlusal surfaces. Additionally, four points were marked on the mesial, distal, buccal, and lingual aspects to assess the marginal fit. [8,9]

Hausdorff distance was calculated for both AI crowns and Exocad crowns to compare their marginal and internal fit (Fig. 7).[13]

Cementation of crown with least discrepancy in internal and marginal fit was done (Fig. 8).

Fig. 1. Tooth preparation for zirconia crown (STL 1)

Fig. 2. Crown designing with EXOCAD

Fig. 3. Crown designing with DENTBIRD software

Fig. 4. Scan intaglio and external surfaces of crown with reference body (STL 2A)

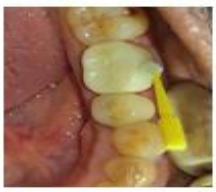

Fig. 5. Scan of crown on abutment tooth. (STL 3A)

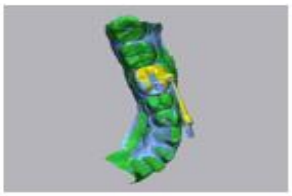

Fig. 6. Superimposition of 3 STL files (AI designed)

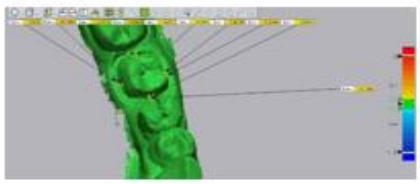

Fig. 7. Analysis of crowns using Geomagic Control X software

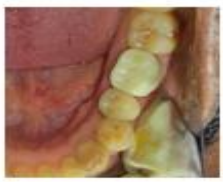

Fig. 8. Final cementation of crown

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RESULTS AND STATISTICAL ANALYSIS

Statistical analysis was conducted using Statistical Product and Service Solutions (SPSS) version 21 for Windows (SPSS Inc., Chicago, IL). Descriptive quantitative data were expressed as means and standard deviations. The normality of the data was assessed using the Shapiro-Wilk test. A confidence interval of 95% was established, with a significance level (alpha error) set at 5%. The study's power was determined to be 80%.

For intergroup comparisons regarding qualitative study parameters, the Chi-square test was utilized. In contrast, intergroup comparisons for quantitative study parameters were performed using the unpaired t-test.

Table 1: Comparison of internal fit between AI and CAD-CAM

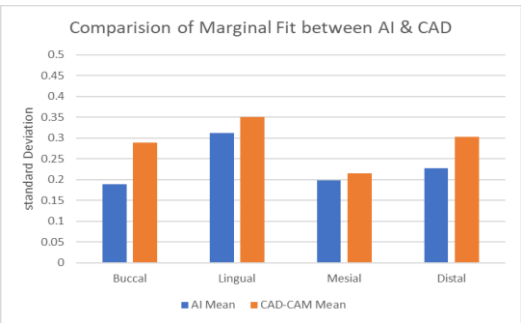
	AI Mean (SD)	CAD-CAM Mean (SD)	Unpaired t test	P value, Significance
Buccal	0.143 (0.019)	0.188 (0.015)	t = -5.659	p<0.001**
Lingual	0.163 (0.049)	0.164 (0.037)	T =-0.079	p=0.938 (NS)
Mesial	0.141 (0.037)	0.17 (0.12)	t = -0.735	p=0.472 (NS)
Distal	0.145 (0.027)	0.221 (0.039)	t = -5.006	p<0.001**
Occlusal	0.099 (0.035)	0.112 (0.014)	t = -1.012	p=0.325 (NS)

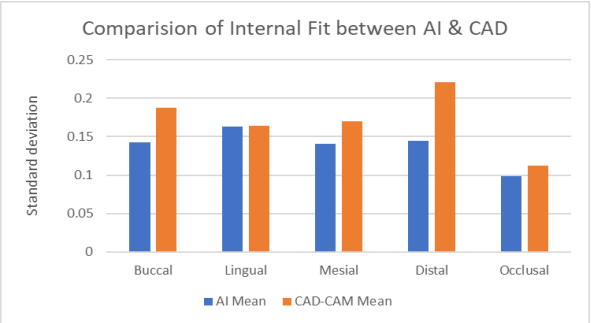
The results stated AI to have a superior internal fit accuracy compared to CAD-CAM. Specifically, AI was statistically significantly better (p<0.001) in the buccal and distal regions. While AI also showed better internal fit in the lingual, mesial, and occlusal regions, no significant differences were found between these two methods (p>0.05)

Table 2: Comparison of marginal fit between AI and CAD-CAM

	AI Mean (SD)	CAD-CAM Mean (SD)	Unpaired t test	P value, Significance
Buccal	0.189 (0.061)	0.289 (0.072)	t = -3.306	p=0.004*
Lingual	0.312 (0.155)	0.35 (0.105)	t = -0.633	p=0.534 (NS)
Mesial	0.198 (0.111)	0.216 (0.121)	t = -0.352	p=0.729 (NS)
Distal	0.227 (0.055)	0.303 (0.042)	t = -3.407	p=0.003*

The results indicated that AI demonstrated better marginal fit accuracy compared to CAD-CAM. Specifically, AI was statistically significantly superior (p<0.001) to CAD-CAM in the buccal and distal regions. Additionally, while AI also exhibited better marginal fit in the mesial and lingual regions, no significant difference was found between the two methods in these areas (p>0.05).





Discussion

The study was conducted to assess the internal fit and marginal fit in comparison with AI crown and CAD crown. According to the study's findings, higher values of internal fit and marginal fit of CAD crown observed with that of AI fabricated crown. Therefore, null hypothesis is rejected.

A substantial marginal gap between a dental restoration and the underlying tooth can result in leakage and recurrent caries. Consequently, the presence of a

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marginal gap is a critical factor to consider when selecting a method for fabricating dental crowns, particularly with the advent of new technologies. Despite meticulous preparation, some degree of gap between the margin of a full-coverage restoration and the finish line of the prepared tooth is inevitable. The existing literature indicates that an acceptable marginal gap should be less than 120 µm.[10,11]

Other methods have been developed for *in vivo* use, overcoming the limitations of *in vitro* assessment methods for the marginal fit of dental prostheses. Among them are the Silicone Replica Technique (SRT), Dual Scan Method (DSM), Triple-scan Method (TSM), and Optical Coherence Tomography (OCT). The silicone replica technique and the triple-scan protocol can both be used to assess the fit of tooth-supported restorations. However, when using the triple-scan protocol for measuring the absolute marginal gap, the scanner employed must be capable of capturing scan points at the outermost edge of the restorations.[12,7]

AI-designed crowns showed significantly better internal fit at the buccal (0.143 mm) and distal (0.145 mm) regions compared to CAD-CAM crowns (0.188 mm and 0.221 mm, respectively), with $p < 0.001$, indicating improved adaptation in key functional areas. In this study, AI-designed zirconia crowns showed significantly better marginal fit than CAD-CAM crowns in the buccal and distal regions. The buccal and distal discrepancies were lower in the AI group (0.189 mm and 0.227 mm) compared to the CAD-CAM group (0.289 mm and 0.303 mm), with p-values of 0.004 and 0.003, respectively, which is in accordance with Kızılkaya and Kara.

Recent studies have investigated the integration of artificial intelligence (AI) into prosthetic design, particularly crown fabrication. Wu et al. (2024)[14] compared AI-powered design systems with traditional manual CAD techniques, finding that AI significantly reduced design time while revealing a potential drawback: lower accuracy in the distal regions of restorations due to AI's limitations in complex anatomical learning. In contrast, Liu et al. (2024)[15] assessed the efficiency and fit of AI-generated crowns, noting a reduction in design time of up to 900% compared to conventional methods, while maintaining clinically acceptable internal and marginal fits. This suggests that AI enhances workflow speed without compromising necessary precision. Chau et al. (2024)[16] further advanced the field by exploring the use of Generative Adversarial Networks (GANs) in dental prosthesis design. Their research indicated that GAN-generated crowns achieved approximately 60% morphological accuracy compared to ideal forms. Although this level of precision is not yet optimal for clinical applications, it demonstrates the growing potential of AI and generative models in producing functionally relevant designs with minimal human intervention.

This study has certain limitations. Firstly, the small sample size constrains the generalizability of the findings. Additionally, the evaluation focused solely on mandibular molars, which may not accurately reflect outcomes for other dental types. The comparison was limited to one AI-based software and one conventional CAD/CAM software, potentially making the findings inapplicable to other systems. The involvement of operators in both the scanning and crown placement processes could have introduced variability into the results. Moreover, the assessment of fit was conducted at selected measurement points, which may not adequately capture the comprehensive adaptation of the crown. Lastly, only the immediate fit was evaluated, without any consideration for long-term clinical follow-up.

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