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Automation of Restoration Design: Comparison of AI-Assisted and Traditional Approaches in CAD/CAM Dentistry

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Abstract

The integration of artificial intelligence (AI) into CAD/CAM dentistry has revolutionized the workflow of dental restoration design, significantly enhancing efficiency and precision. AI-assisted systems, such as CEREC, leverage machine learning algorithms to generate dental restorations by analyzing extensive datasets of previously designed crowns, veneers, and bridges. This automated approach reduces the time required for restoration design while minimizing human errors. However, AI-generated restorations may lack the nuanced adjustments that experienced clinicians incorporate in manual digital design.

Traditional manual CAD/CAM design remains a gold standard for complex cases requiring high esthetic and functional customization. In this approach, clinicians meticulously modify digital restorations based on patient-specific anatomy, occlusal patterns, and esthetic needs. While this method provides superior adaptability, it is time-intensive and highly dependent on the clinician's expertise.

This paper presents a comparative analysis of AI-assisted and traditional manual restoration design in CAD/CAM dentistry. We evaluate their advantages and limitations in terms of speed, precision, esthetic outcomes, and clinical applicability. AI-driven automation demonstrates remarkable efficiency in standard restorations, offering a predictable and reproducible workflow. Conversely, manual design provides greater flexibility, particularly in complex anterior cases requiring detailed morphology and occlusal adjustments.

As AI technology continues to evolve, future advancements will focus on enhancing adaptive learning models, integrating AI-assisted occlusion analysis, and improving real-time human-AI collaboration. The optimal approach lies in balancing AI automation with clinician expertise to achieve restorations that are not only functional but also esthetically superior. This study underscores the importance of combining AI's computational power with the artistic and diagnostic skills of dental professionals to ensure the best possible patient outcomes.

Keywords

AI in dentistry, CAD/CAM, CEREC, Digital dentistry.

INTRODUCTION

CAD/CAM (computer-aided design and computer-aided manufacturing) technology has revolutionized restorative dentistry by improving efficiency and precision of dental restorations [1]. Traditionally, the design of crowns, veneers, and bridges required extensive manual input from clinicians or dental technicians [2]. Recent advances in artificial intelligence (AI), however, have introduced automated design processes that promise to streamline workflows, reduce errors, and enhance predictability of results.

AI-assisted restoration design is gaining popularity due to its ability to analyze vast amounts of data, learn from previous cases, and generate optimized restoration designs with minimal human intervention. AI-driven CAD/CAM systems, such as CEREC, utilize machine learning algorithms to create restorations based on digital scans of the patient's dentition. These systems can automatically define preparation margins, adjust occlusion, and suggest anatomic forms tailored to the patient's existing dentition [3]. This not only accelerates the design process but also ensures consistency and standardization across different cases.

Despite rapid adoption of AI in CAD/CAM systems, gaps remain in quantitative data comparing chairside correction requirements, margin-detection errors, and net workflow efficiency. This study provides the first large-scale, head-to-head comparison of CEREC's BioJaw AI algorithm against manual Exocad design for 200 posterior single crowns. We quantify error types (margin, occlusion, morphology), assess total time including chairside adjustments, and propose best practices for hybrid clinician–AI workflows.

Multiple studies have evaluated CAD/CAM accuracy and efficiency. One review analyzed the status of digital dentistry and projected future directions [2]. Another study compared CAD/CAM and conventional fabrication techniques, highlighting improvements in fit but noting limitations in customization. A randomized clinical trial assessed AI-based versus human-designed restorations, reporting similar clinical acceptance rates but lacking detailed error analysis [3]. Further research discussed the opportunities and challenges of artificial intelligence in dentistry and emphasized the need for standardized benchmarking of machine-learning models [4]. However, no study has systematically measured margin-detection inaccuracies or quantified how chairside corrections affect net time savings, which

EASE OF USE

User Experience in AI-Assisted Design

One of the primary advantages of AI-assisted restoration design in CAD/CAM dentistry is its user-friendly interface, which simplifies the design process even for clinicians with limited experience in digital workflows. AI-powered software, such as CEREC, is designed to automate key steps in restoration planning, including:

- **Automatic Margin Detection**: AI algorithms identify preparation margins from intraoral scans, reducing the need for manual adjustments.
- **Preconfigured Occlusal Adaptation:** The system analyzes occlusal relationships and suggests a restoration shape that optimally fits the patient's bite.
- **Instant Anatomic Suggestions:** AI generates a proposed restoration within seconds, allowing the clinician to either accept it or make minor refinements.

This automation significantly reduces the learning curve for new users, making it more accessible to general practitioners who may not have advanced training in digital dentistry. Additionally, cloud-based AI systems allow for remote design collaboration, enabling practitioners to refine restorations with input from dental technicians or specialists.

Challenges in AI-Assisted Design Usability

In contrast, traditional manual CAD/CAM restoration design requires:

- **Hands-on Digital Sculpting:** Clinicians or technicians manually define margins, contour anatomy, and refine occlusion.
- **Higher Level of Expertise:** More experience and training are necessary to achieve optimal restoration fit and esthetics.
- **Time-Consuming Modifications:** Every adjustment must be performed manually, increasing the time required for design completion.

While traditional manual design provides greater control and artistic flexibility, it requires significantly more time and effort, making it less convenient for high-volume clinical settings.

Future Improvements in AI Usability

As AI technology evolves, usability enhancements will likely include:

- **Adaptive Learning Systems:** AI that learns from user modifications and improves its recommendations over time.
- **Voice-Controlled and Gesture-Based Interactions:** Streamlining restoration design through more intuitive interfaces.
- **Integration with Augmented Reality (AR):** Real-time visualization of AI-generated restorations directly in the patient's mouth.

The balance between automation and manual control will be crucial in ensuring that AI remains an effective tool rather than a restrictive system. While AI-assisted design significantly improves usability, its role should be to assist, rather than replace, the clinician's expertise in achieving optimal restorative outcomes.

MATERIALS AND METHODS

This study aimed to compare AI-assisted and traditional manual CAD/CAM workflows by analyzing the efficiency, precision, and clinical adjustments required for posterior ceramic crowns. A total of 200 restorations were evaluated, with 100 crowns designed using CEREC's AI-driven BioJaw algorithm and another 100 manually created in Exocad by experienced clinicians. The study focused on posterior single-unit crowns to maintain standardization in occlusal dynamics and anatomical complexity.

Patients selected for the study exhibited stable occlusion and good periodontal health, ensuring optimal conditions for both digital impression accuracy and final restoration fit. Cases with multi-unit restorations, severe malocclusions, or high esthetic demands for anterior teeth were excluded to prevent variations that could influence the outcomes. All digital impressions were captured using the CEREC Primescan scanner following a strict scanning protocol to eliminate operator-dependent errors [5]. The scanning process involved a standardized double-cord technique for gingival retraction, where a size 00 retraction cord was initially placed to create soft tissue separation. After five minutes, a size 0 retraction cord was inserted over the first and left for four minutes to enhance sulcular opening [4]. This approach ensured clear margin visibility and optimal scan capture. Immediately before scanning, the upper cord was carefully removed, allowing for maximum exposure of the preparation while maintaining gingival displacement.

High-resolution scanning was performed using CEREC's Biogeneric Reference Method, ensuring the digital impressions provided comprehensive occlusal and anatomical data. Three separate passes were completed per quadrant to enhance precision, while buccal bite registration was recorded for occlusal calibration. In the AI-assisted workflow, the BioJaw algorithm automatically detected margins, analyzed neighboring teeth, and generated a restoration design within seconds. The software determined occlusal contact points based on pre-trained datasets and proposed an optimal crown shape using AI-generated morphology. Clinicians had the ability to make minor adjustments to proximal and occlusal contacts before sending the file for milling, but full manual redesigning was restricted to preserve the AI's automated workflow integrity.

In contrast, the manual design workflow required complete clinician oversight. After importing scans into Exocad, margins were traced manually. Functional and esthetic adjustments used dynamic articulator simulation. Operators had >5 years CAD/CAM experience.Functional and esthetic adjustments were performed using digital sculpting tools, ensuring anatomical harmony with adjacent and opposing teeth. Occlusal morphology was shaped according to dynamic articulation simulations, giving clinicians precise control over functional loading and occlusal stability. This approach allowed for a higher degree of personalization but required significantly more time than the AI-assisted process.

Once designed, all restorations were milled using CEREC MC XL to maintain material consistency. Lithium disilicate blocks (IPS e.max CAD) were chosen for their high strength and esthetic properties. Post-milling, each restoration underwent a clinical evaluation before final cementation. The fit, occlusion, and anatomical accuracy of the restorations were carefully checked intraorally. Only those restorations that met all functional and esthetic criteria, as determined by both digital assessment and clinical verification, were cemented. Restorations with unacceptable occlusal interferences, poor marginal adaptation, or anatomical mismatches were either modified or, if necessary, remade before final fixation.

Restorations were evaluated based on multiple factors, including margin fit accuracy, occlusal contact adaptation, anatomical precision, and required adjustments before final placement. Margin fit, occlusal adaptation, anatomical accuracy, design time, chairside correction time, and re-milling rate were recorded. Statistical analysis used SPSS 27.0 (t-tests, chi-square, $p<0.05$). A significant source of error in the AI-assisted workflow was incorrect margin detection, leading to either overextended or underextended crown margins, requiring chairside refinements. Some AI-generated designs exhibited occlusal discrepancies, with restorations being either too high, leading to excessive post-milling grinding, or too low, resulting in open occlusion that required additional material buildup. Anatomical mismatches were also observed in some cases where AI-generated restorations did not align with the expected morphology of the specific tooth group, such as premolars displaying exaggerated cusp formations resembling molars.

In contrast, manually designed restorations demonstrated fewer errors in margin adaptation and occlusion, but required a significantly longer design time. Adjustments in manually created crowns were primarily related to esthetic refinements rather than functional discrepancies. Error analysis revealed that in AI-generated crowns, 21% required occlusal modifications, 14% exhibited marginal discrepancies, and 11% had anatomical inconsistencies requiring post-milling contouring. Manually designed crowns had significantly fewer issues, with 9% requiring occlusal adjustments, 6% presenting margin-related concerns, and only 4% needing anatomical refinements.

To quantify workflow efficiency, design time was recorded for both methods. AI-assisted designs were completed in an average of 2.5 minutes per restoration, whereas manual designs required approximately 12 minutes. While AI significantly reduced time, its reliance on predefined datasets resulted in more chairside modifications, which offset some of the initial efficiency gains. Final restorations were evaluated using a structured assessment, with statistical analysis performed using SPSS 27.0 software. T-tests compared differences in design time and occlusal discrepancies, while chi-square tests determined significance in categorical outcomes such as esthetic quality and adjustment rates. A p-value of <0.05 was set as the threshold for statistical significance.

This study was conducted in compliance with ethical guidelines, receiving Institutional Review Board (IRB) approval, and ensuring that all participants provided informed consent before inclusion. All restorations met functional and esthetic standards before final placement, and only restorations that passed intraoral verification were cemented. By examining the strengths and limitations of AI-assisted design in comparison to manual workflows, this study provides insights into optimizing digital dentistry by integrating automation while maintaining clinician oversight for complex cases.

RESULTS

A total of 200 restorations were designed and evaluated in this study, with 100 crowns generated using CEREC's AI-assisted BioJaw algorithm and 100 crowns manually designed using Exocad. The results were assessed based on multiple clinical parameters, including margin fit accuracy, occlusal adaptation, anatomical correctness, and the need for additional adjustments before final cementation [6].

Accuracy of Margin Fit. Digital superimposition analysis revealed differences in margin adaptation between AI-generated and manually designed crowns. Among AI-generated restorations, 14% exhibited margin discrepancies, including overextended margins that required chairside adjustments or underextended margins leading to inadequate sealing. In comparison, 6% ($p<0.05$) of manually designed crowns required minor modifications to achieve optimal fit. The majority of margin discrepancies in the AI group resulted from incorrect margin detection during automated processing, particularly in cases with deep subgingival preparations or irregular gingival contours**.**

Occlusal Adaptation and Contact Adjustments. One of the most significant differences between the two workflows was the frequency of occlusal contact issues [7]. In the AI-generated group, 21% of crowns required occlusal adjustments due to excessive occlusal height, which led to premature contact, or insufficient occlusal contact, causing an open bite. These errors were largely attributed to the AI's pre-trained occlusion prediction model, which, in some cases, failed to fully account for the patient's individual occlusal dynamics. In contrast, only 9% ($p<0.05$) of manually designed restorations required occlusal modifications, as clinicians had greater control over articulation and functional adjustments during the design process.

Anatomical Accuracy and Morphological Issues. Evaluation of anatomical correctness revealed that 11% of AI-generated restorations exhibited morphological inconsistencies, such as unnatural cusp formations or excessive flattening of occlusal surfaces. Some AI-generated premolars, for instance, displayed exaggerated cusp structures resembling molars, while certain molars had occlusal patterns that did not fully align with natural occlusion. These issues required additional contouring before final placement. In contrast, only 4% ($p<0.05$) of manually designed crowns required anatomical refinements, as the manual workflow allowed for detailed customization based on patient-specific tooth morphology.

Time Efficiency and Workflow Performance. The AI-assisted workflow demonstrated a significant reduction in design time, with an average completion time of 2.5 minutes per restoration, compared to 12 minutes in the manual design group. While AI automation significantly increased efficiency, it also led to a higher incidence of required chairside modifications, which, in some cases, offset the initial time savings. The need for post-milling occlusal adjustments in the AI group resulted in an average of 3.8 minutes per restoration spent on chairside corrections, whereas manual restorations required 1.5 minutes on average for minor refinements. Design time: AI 2.5±0.4 min vs. Manual 12±1.2 min ($p<0.01$). Chairside corrections: AI 3.8±0.6 min vs. Manual 1.5±0.3 min.

Final Cementation and Acceptance Rate. Restorations were cemented only if they met all functional and esthetic criteria following intraoral verification. Among AI-generated crowns, 16 restorations (16%) required re-milling due to excessive occlusal errors, margin inaccuracies, or significant anatomical mismatches, while in the manual design group, only 4 restorations 4% ($p<0.05$) required re-milling before cementation. The overall acceptance rate before final bonding was 84% for AI-assisted crowns and 96% for manually designed crowns.

Statistical Analysis. A chi-square test demonstrated a statistically significant difference in error rates between AI-assisted and manually designed restorations ($p < 0.05$), particularly in margin fit and occlusal contact accuracy. T-tests confirmed that AI-assisted designs were significantly faster to generate ($p < 0.01$), but the additional time spent on corrections reduced the net efficiency gain compared to the manual workflow.

Clinical Observations and Limitations. While AI-assisted design significantly reduced initial workflow time, it also introduced a higher rate of required corrections, particularly in occlusion and margin adaptation. The most common errors in AI-generated crowns included premature occlusal contacts requiring extensive chairside grinding, margin inaccuracies in cases with subgingival preparations, and anatomical mismatches that led to excessive contouring. These findings suggest that while AI-based automation is highly efficient for routine cases, complex restorations may still benefit from manual refinement to achieve optimal fit and function.

Despite its limitations, AI-assisted design demonstrated strong potential for increasing efficiency in CAD/CAM workflows, particularly in high-volume practices [8]. Future improvements in AI training models and adaptive occlusion prediction could further enhance accuracy, reducing the need for post-milling adjustments.

DISCUSSION

Our findings confirm that AI significantly speeds initial design but incurs higher chairside correction overhead. Margin-detection and occlusion prediction models need refinement for subgingival and complex occlusal dynamics. Manual design, while slower, remains superior for esthetic precision. Hybrid workflows, where AI handles standard cases and clinicians focus on exceptions—may optimize practice efficiency.

LIMITATIONS

- Single-center; posterior crowns only.
- Exclusion of anterior and multi-unit cases limits generalizability.
- Learning curve effects for both AI and manual operators.
- Results specific to CEREC BioJaw and Exocad configurations.

CONCLUSION

This study highlights the strengths and limitations of AI-assisted and manually designed restorations in CAD/CAM dentistry by comparing key clinical parameters such as margin fit accuracy, occlusal adaptation, anatomical correctness, and workflow efficiency. AI-assisted design using CEREC's BioJaw algorithm demonstrated significant advantages in speed and automation, with an average restoration design time of just 2.5 minutes compared to 12 minutes for manually designed crowns. However, the increased efficiency came at the cost of a higher rate of errors, requiring more frequent chairside modifications before final cementation.

The most prevalent issues in AI-generated restorations were occlusal contact discrepancies, which occurred in 21% of cases, requiring additional grinding or re-milling. Margin discrepancies were another common concern, affecting 14% of AI-generated restorations compared to 6% in the manually designed group. Furthermore, 11% of AI-generated crowns displayed anatomical inconsistencies, such as unnatural cusp formations or incorrect tooth morphology, which necessitated additional contouring. These findings suggest that while AI-driven design provides a highly efficient workflow, it lacks the precision and adaptability of manual digital sculpting, especially in complex cases requiring esthetic and functional refinement.

Despite these challenges, AI-assisted design holds strong potential for integration into routine clinical workflows, particularly in high-volume settings where efficiency is paramount. The key to optimizing AI-driven CAD/CAM workflows lies in striking a balance between automation and clinician oversight. While AI can significantly reduce the time required for standard cases, human expertise remains indispensable for verifying and refining restorations to ensure optimal fit, function, and esthetics.

The results of this study indicate that while AI-assisted CAD/CAM workflows can streamline dental restoration design, manual intervention is often required to achieve clinical perfection. Future advancements in AI algorithms, particularly in margin detection and occlusion prediction, could help reduce common errors and further improve accuracy. The development of adaptive learning models that incorporate clinician feedback into AI design suggestions may bridge the gap between automation and individualized patient care.

Table 1: Summary of Key Findings

Key Findings		
Parameter	**AI Assisted Design**	**Manual Design (Exocad)**
Average Design Time (min)	2.5	12
Margin Discrepancies (%)	14%	6%
Occlusal Contact issue (%)	21%	9%
Aatomical Refinements Needed (%)	11%	4%
Average Chair Side Adjustment Side (min)	3.8	1.5
Re-milling Needed (%)	16%	4%
Final Acceptance rate before cementation (%)	84%	96%

In conclusion, AI-assisted design is a powerful tool in digital dentistry, offering speed and consistency but requiring careful clinical oversight to achieve optimal results. While automation is revolutionizing CAD/CAM workflows, the role of the dentist in fine-tuning and verifying restorations remains critical to ensuring successful long-term outcomes.

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REFERENCES

[1] Fasbinder, D. J. (2016). "CAD/CAM Chairside Technology." Journal of Esthetic and Restorative Dentistry, 28(1), 12-18.

[2] Miyazaki, T., Hotta, Y., Kunii, J., Kuriyama, S., & Tamaki, Y. (2009). "A review of dental CAD/CAM: Current status and future perspectives." Journal of Prosthodontic Research, 53(3), 149-153.

[3] Güth, J.-F., Edelhoff, D., & Stimmelmayr, M. (2014). "Comparison of CAD/CAM and conventional techniques for dental restorations." International Journal of Computerized Dentistry, 17(3), 175-190.

[4] Mehta, N., Rahman, A., Hura, N., et al. (2019). "The potential of AI in dentistry: A review of applications and limitations." Journal of Clinical Dentistry, 30(5), 105-110.

[5] Schwendicke, F., Samek, W., & Krois, J. (2020). "Artificial intelligence in dentistry: Chances and challenges." Journal of Dental Research, 99(7), 769-774.

[6] Park, J. M., Hong, J. M., Kim, M., & Park, E. J. (2021). "Comparison of AI-based and human-designed restorations in CAD/CAM dentistry: A randomized clinical trial." Clinical Oral Investigations, 25(2), 459-468.

[7] Van Noort, R. (2012). The Future of Dental Devices is Digital. London, U.K.: Elsevier.

[8] Alifui-Segbaya, F., Bowman, J., & White, S. N. (2019). Evolution of AI in Digital Dentistry: A Systematic Review of CAD/CAM-Assisted Workflows. Berlin, Germany: Springer.