WWW.IJRPR.COM

International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Prosthodontics in the Age of Artificial Intelligence Opportunities and Challenges

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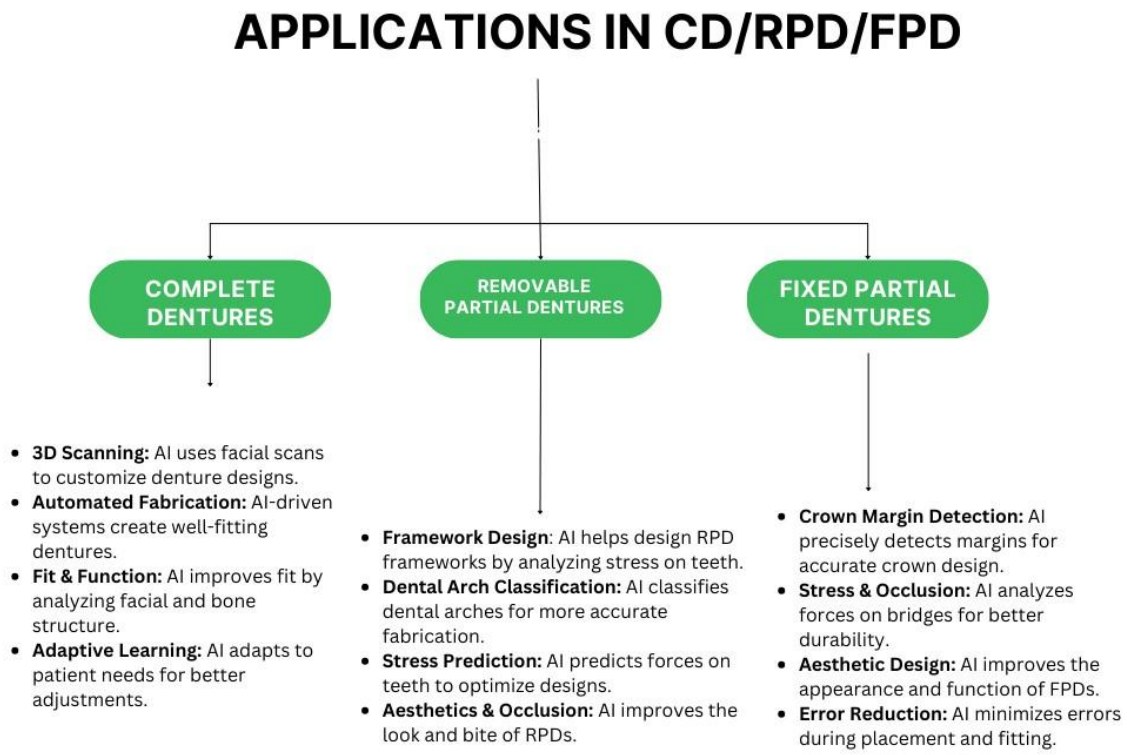
ABSTRACT

The integration of Artificial Intelligence (AI) into prosthodontics is revolutionizing the field by enhancing diagnostic accuracy, treatment planning, and prosthetic design. This review explores the transformative impact of AI and Machine Learning (ML) on dental prosthodontics. AI applications, including deep learning, convolutional neural networks (CNNs), and generative adversarial networks (GANs), have significantly improved various aspects of prosthodontic practice. Recent studies demonstrate AI's effectiveness in detecting dental restorations, predicting facial deformation, and designing customized prosthetics with high accuracy. AI-driven tools also optimize Cone Beam Computed Tomography (CBCT) and 3D imaging for better implant diagnostics and surgical planning. Despite these advancements, challenges such as high costs, data privacy concerns, and the need for improved explainability of AI models persist. Future developments in AI are expected to further enhance the precision of dental prostheses and improve patient outcomes, while addressing current limitations and ethical considerations. This review underscores the potential of AI to advance prosthodontics and highlights the need for ongoing research to ensure responsible and effective integration into clinical practice.

Keywords: Artificial Intelligence, Machine Learning, Prosthodontics, Deep Learning, Convolutional Neural Networks

Introduction

Prosthodontics, the branch of dentistry focused on designing and fitting artificial replacements for missing teeth, is experiencing significant transformations due to advancements in artificial intelligence (AI). This specialized field, which focuses on designing and fitting artificial replacements for missing teeth, has seen significant progress with the advent of cutting-edge technologies.[1] One of the most impactful advancements in recent years is the integration of Artificial Intelligence (AI) and Machine Learning (ML) into Prosthodontics. AI, defined as the development of computer systems that work in conjunction with human intelligence, aims to create machines capable of performing tasks traditionally managed by humans. Within AI, Machine Learning (ML) plays a crucial role by applying algorithms to identify and learn patterns in data, which facilitates predictions and decisionmaking. Among ML models, neural networks (NNs) and deep learning architectures have shown remarkable efficacy in handling complex data structures, such as imagery and language. In Prosthodontics, AI's influence is becoming increasingly evident.[2,3] The use of AI in Cone Beam Computed Tomography (CBCT) and 3D imaging has revolutionized implant prosthodontic diagnostics, allowing for more precise and accurate assessments. The application of AI in designing surgical templates and evaluating bone quality has produced exceptional results, enhancing the efficacy of treatment planning. Furthermore, advancements in Computer-Aided Design (CAD) and Computer-Aided Manufacturing (CAM), combined with Rapid Prototyping (RP) technologies, have greatly improved the precision and customization of prosthetic devices. The introduction of AI-driven generative adversarial networks (GANs) has further elevated the field, enabling laboratories to automatically generate advanced dentistry . AI has made notable strides in prosthodontics by improving the processes involved in creating both removable and fixed prostheses, refining finish margins, selecting appropriate colors, designing implant and maxillofacial prostheses, and ensuring stable maxilla-mandibular relationships. Unlike traditional prosthodontics, which depends on human expertise and visual-tactile methods, AI has enhanced the precision, accuracy, and reliability of these procedures, leading to better clinical outcomes. More dental practices, institutions, and educational centers are now adopting 3D digital dentistry, reflecting AI's growing influence in the field. These AI-generated designs ensure optimal fit, function, and aesthetics, marking a significant leap forward in both Prosthodontics and maxillofacial prosthodontics. As virtual technologies continue to evolve, they are gradually becoming a reality in Prosthodontics. The integration of AI not only enhances the accuracy and efficiency of prosthetic fabrication but also pushes the boundaries of what is possible in prosthetic rehabilitation.[4,5] This article explores the opportunities and challenges in prosthodontics for the adoption of artificial intelligence



Review of literature

In recent advancements in dental prosthodontics, several studies have explored the integration of artificial intelligence (AI) and machine learning (ML) to enhance various aspects of dental care. Lee from Korea evaluated the efficacy of deep convolutional neural networks (CNNs) for identifying and classifying dental implant systems using panoramic and periapical radiographic images, finding that the CNN architecture, specifically GoogLeNetInception v3, was highly effective.[6] Lerner from Germany focused on the use of AI for fabricating implantsupported monolithic zirconia crowns with a digital workflow, noting that intrinsic AI algorithms in CAD software, such as Valletta® and Exocad, achieved very accurate marginal adaptation in 96.2% of cases.[7] Yamaguchi in Japan assessed the performance of deep learning CNNs in predicting the debonding probability of CAD/CAM from 2D images derived from 3D STL models, achieving a remarkable prediction accuracy of 98.5%.[8],[9],[10]Raith from Germany investigated the potential of artificial neural networks (ANNs) for tooth classification, finding high performance in automatic cusp detection and classification, which supports standardized treatment concepts in evidence-based dentistry.[11] Wei in China explored a novel computer color-matching system using an improved back-propagation neural network model, which achieved greater accuracy in color reproduction compared to traditional visual methods.[12] These studies collectively highlight the significant impact of AI and ML in advancing diagnostic accuracy, treatment planning, and overall efficiency in dental prosthodontics.

Recent advancements in dental prosthodontics through AI and ML have significantly improved diagnostic accuracy and prosthetic design. Studies by Takahashi et al. achieved high accuracy in detecting crown restorations[13], while Cheng et al. demonstrated effective prediction of facial deformation after denture placement using back-propagation neural networks.[14] Deniz S et al. used artificial neural networks to predict surface roughness and microhardness of denture teeth.[15] Li et al. applied evolutionary algorithms to predict the flexural strength of CAD/CAM composites.[16] Yuan F et al. predicted aesthetic outcomes for edentulous patients[17], and Yang J et al.[18] forecasted colors and thicknesses of CAD-CAM ceramics with high accuracy. Chau R et al. employed generative adversarial networks to automate single-molar prosthesis design.[19] Chen Q et al. used a knowledge-based clinical support system for designing removable partial dentures.[20]Matin et al. improved casting metal substructure manufacturing time, while Mine et al. compared random forest and deep learning for color matching in maxillofacial prosthetics.[21,22] Choi et al. achieved 100% accuracy in extracting tooth preparation marginal finish lines[23], Ding et al. used 3D deep convolutional generative adversarial networks for dental crown design[24], Liu evaluated AI in designing dental restorations, noting improved efficiency and accuracy.[25] These advancements collectively enhance production efficiency, accuracy, and overall treatment outcomes in dental prosthodontics.

Review of Literature on AI in Dental Prosthodontics

Researcher(s)	Country	Area of Study	AI Technology Used	Outcome
Lee et al.	Korea	Classification of dental implant systems	CNN (GoogLeNet-Inception v3)	High accuracy in identifying dental implants using radiographic images
Lerner et al.	Germany	Fabrication of implant-supported crowns	AI in CAD software (Valletta®, Exocad)	Achieved 96.2% accuracy in marginal adaptation
Yamaguchi et al.	Japan	Prediction of debonding probability in CAD/CAM	Deep Learning CNN	98.5% accuracy in debonding prediction
Raith et al.	Germany	Tooth classification	High performance in Artificial Neural Networks (ANNs)	cusp detection and classification
Wei et al.	China		Color matching in prosthetics	Improved accuracy in Back-propagation color reproduction neural network compared to traditional methods
akahashi et al.	Japan	Detection of crown restorations	Deep Learning	High accuracy in detecting crown restorations
Cheng et al.	China	Prediction of facial deformation after denture placement	Back-propagation neural networks	Effective prediction of facial deformation post-denture placement

Deniz S et al.	Turkey	Surface roughness and microhardness prediction	Artificial Neural Networks (ANNs)	Accurate prediction of surface properties of denture teeth	
Li et al.	China	Prediction of flexural strength of composites	Evolutionary CAD/CAM algorithms	Accurate flexural strength prediction	
Yuan F et al.	China	Aesthetic outcomes for edentulous patients	Accurate prediction of Machine Learning	aesthetic outcomes	

Researcher(s)	**Country**	**Area of Study**	**AI Technology Used**	**Outcome**	
Yang J et al.	China	Forecasting color and thickness in ceramics	High accuracy in CAD/CAM	Machine Learning	predicting color and
Chau R et al.	USA	Automated design with high efficiency design	single- molar prosthesis	Generative Adversarial Networks (GANs)	
Chen Q et al.	China	Knowledge-based system	Design of removable partial dentures	Improved clinical RPD design	accuracy in support
Matin et al.	Iran	Manufacturing time improvement for metal substructures	AI-Enhanced Workflow	Faster time	manufacturing
Mine et al.	Japan	Color matching in maxillofacial	Random Forest, Deep Learning	Improved color matching	accuracy in

		prosthetics			
Choi et al.	Korea	Tooth marginal extraction	preparation AI finish detection	for line extraction	margin 100% accuracy in margin
Ding et al.	China	3D Improved crown design Dental crown design process	Deep Convolutional GANs		
Liu et al.	China	Enhanced efficiency and accuracy in restoration design	Dental AI-driven systems design	restoration	

Opportunities in Prosthodontics

AI improves diagnostic capabilities and treatment outcomes through predictive modeling and real-time feedback during procedures. AI facilitates the creation of patient-specific prostheses, enhancing the fit and functionality of dental appliances. The use of AI and robotics in prosthodontics increases accuracy and reduces errors in procedures, leading to better patient care. AI has shown promising results in automated diagnostics, especially in dental imaging, with high performance in detecting dental caries and predicting debonding of CAD/CAM crowns[26]. AI can predict treatment outcomes such as soft tissue changes after denture placement and the physical properties of dental materials, potentially leading to more accurate and personalized treatment plans. AI technologies can automate complex tasks such as the design of dental prostheses, occlusal surface design, and framework design, which could streamline workflows and enhance clinical and laboratory productivity. AI systems are adept at handling large volumes of data, which can improve classification outcomes and assist in evidence-based decision-making, particularly for less experienced practitioners. AI can support educational efforts by assisting undergraduate students and practitioners in learning and applying complex prosthodontic concepts. AI can facilitate the design of dental prostheses by accounting for various intraoral factors and improving the customization of prosthetics.[27]

Applications in Prosthodontics

Application Area	**AI Contribution**
Diagnosis	- Processes large amounts of data from 3D scanning and imaging to extract relevant clinical information. - Enhances diagnostic accuracy by identifying problems and suggesting optimal treatment plans. - Early detection of disease and optimization of dental workflow. - Provides insights into prosthetic rehabilitation needs, such as type and design of prosthesis. - Identifies patterns in data that may be challenging for humans to discern, such as periodontal issues with high accuracy.[1,3,4,7]
CAD/CAM Systems	- Integrates with CAD/CAM to design, manufacture, print, or mill prostheses. - Detects margins of crown preparations and automatically labels them. - Analyzes factors like facial proportions and patient expectations to enhance

	aesthetics. - Assists in fabricating crowns and minimizing errors during cementation.[2]
Tooth-Supported Fixed and Removable Prostheses	- Designs various RPD frameworks and components. - Uses CNNs to classify dental arches and assist in RPD fabrication with high diagnostic accuracy. - Analyzes stress on adjacent teeth and implants. - Supports decision-making for inexperienced dentists and enhances occlusal morphology and aesthetics in FPDs. - Extracts margin lines with precision to ensure proper fit and maintenance of periodontal health.[3,4,5]
Implantology	- Utilizes 3D imaging and digital scans to design and fabricate implant prostheses. - Predicts implant success through analysis of osseointegration, risk factors, and bone anatomy. - Identifies stress at the implant-bone interface and assists in aligning implants and prostheses. - Helpsin accuratefabrication and positioning of surgical guides.[2,7]
Maxillofacial Prostheses	- Aids in the fabrication of life-like prostheses by identifying patient preferences and facial dimensions. - Develops advanced prosthetics such as AIpowered prosthetic eyes with sensory capabilities. - Contributes to the development of artificial skin grafts and olfactory systems for improved patient quality of life.[1,3]

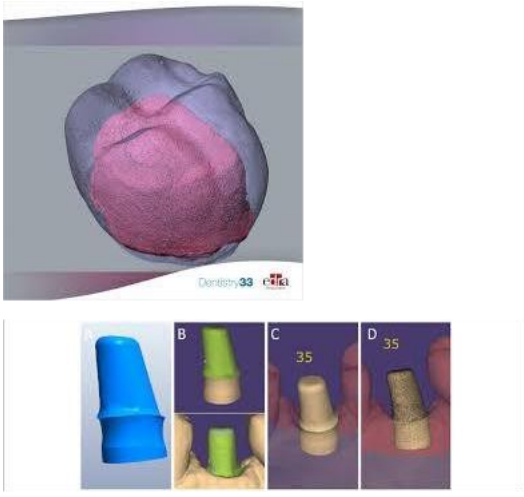


FIG 3: AI IN TOOTH PREPARATION Challenges in Prosthodontics

AI applications in prosthodontics are still largely experimental and limited to test versions, with few systems ready for routine clinical use. The development and standard implementation of AI technologies are often hindered by financial constraints and the rapid turnover of software, making widespread adoption challenging. The heterogeneity in study designs, AI models, and datasets poses difficulties in comparing results and drawing definitive conclusions.[26,27] While AI has shown promise, there are limitations in specific areas such as detecting dental caries and calculus, and current models may not yet be reliable for all clinical scenarios. The cost–benefit ratio and ethical aspects of using patient-specific data need further examination to ensure responsible implementation of AI technologies. There is a need for more studies to enhance the performance of AI models, including improving accuracy and repeatability in prosthodontic tasks.[28] The integration of artificial intelligence (AI) into prosthodontics and broader societal applications presents both promising opportunities and notable challenges. AI's potential to enhance efficiency and precision by automating complex tasks and processing vast amounts of data is significant, yet it also introduces risks such as technical failures due to flawed algorithms or data, which can lead to severe operational issues and unpredictable outcomes. The complexity and self-learning capabilities of AI systems complicate efforts

to anticipate and manage these risks. Additionally, the effectiveness of AI is heavily reliant on the quality of input data, with faulty or biased information potentially skewing results. The "black box" nature of AI systems, which obscures the processes behind their conclusions, further exacerbates concerns about transparency and accountability. There are also substantial costs associated with the initial investment and ongoing maintenance of AI technology.[29] Ethical considerations are paramount, encompassing issues such as data privacy, informed consent, safety, transparency, and algorithmic fairness. Ensuring that AI systems operate within ethical standards and addressing biases and fairness are critical to preventing unjust outcomes and ensuring responsible AI deployment. The challenge of assigning liability for harm caused by AI complicates the discourse on accountability, highlighting the need for clear frameworks and ongoing vigilance as AI technology evolves.[30]

FIG 1: AI IN PROSTHODONTICS

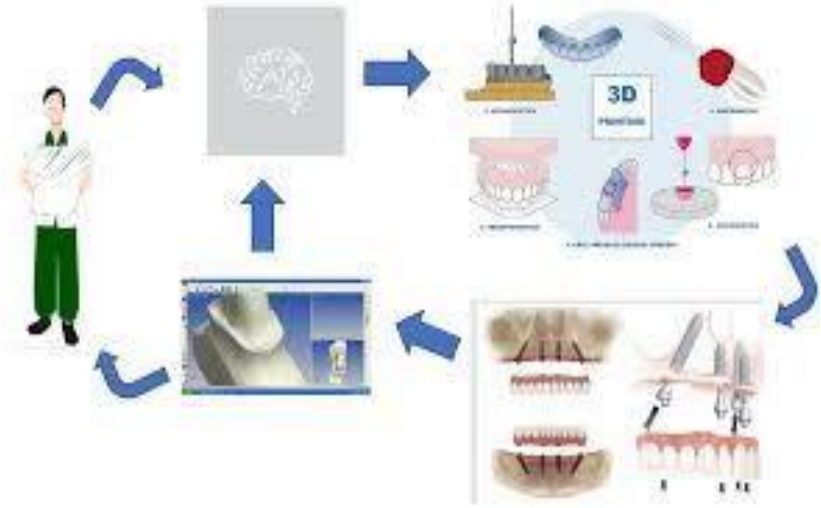


FIG 1: AI IN PROSTHODONTICS -CAD/CAM

Future Directions

The future of artificial intelligence (AI) holds transformative potential across various fields, from space research to dentistry. In the realm of biomedical applications, AI is set to revolutionize diagnosis, therapy planning, patient management, and record-keeping, offering substantial benefits to both physicians and patients. As AI continues to evolve, it is anticipated that future systems will merge predictive capabilities with human expertise, improving diagnostic accuracy and outcomes. Despite promising advancements, it remains crucial to key objective of AI research in dentistry is to enhance models to detect subtle abnormalities that are not visible to the naked eye.[31] As CAD/CAM technology and prosthodontic implant procedures become more precise, the demand for AI-driven algorithms will increase. Explainability in AI development—encompassing pre-modelling, model creation, and postmodelling stages—remains essential. Most current research focuses on post-modelling explainability to interpret the decisions of existing black-box models. For prosthodontists, understanding AI's decision-making processes is crucial for evaluating prosthesis fabrication, though this aspect is not yet fully integrated into practical applications. Future studies should address the explainability of AI to enhance its utility for both practitioners and patients. AI is poised to significantly enhance the clinical and patient experience in dentistry. By learning patient preferences, AI systems can improve the quality of oral health care and, consequently, overall systemic health. Innovations such as AI-driven designs for removable partial dentures (RPDs) and standardized dental implant procedures are expected to modernize and streamline dental therapy. Additionally, AI's potential to decentralize treatment by facilitating remote consultations and improving diagnostic accuracy will lead to more effective and personalized care. Integrating AI predictions with human diagnosis in the future will further refine diagnostic accuracy and treatment efficacy. [4,5,26,29,31]

Conclusion

The integration of Artificial Intelligence (AI) into the field of prosthodontics presents both significant opportunities and challenges. By leveraging AI-powered tools and techniques, prosthodontists can enhance diagnosis, treatment planning, prosthetic design, and patient education. However, addressing concerns related to data privacy, ethical considerations, technical limitations, and regulatory hurdles is crucial for the successful adoption of AI in clinical practice. As AI continues to advance, it is essential for dental professionals to stay informed and adapt to the evolving landscape of prosthodontics.

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