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AI AND MACHINE LEARNING APPLICATIONS IN PROSTHODONTICS: A REVIEW

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ABSTRACT
Artificial Intelligence (AI) and machine learning (ML) are increasingly finding applications across various healthcare fields, including dentistry. In prosthodontics, AI has the potential to revolutionize diagnosis, treatment planning, and prosthesis design. This review explores the current applications of AI in prosthodontics, discusses the benefits and challenges, and examines future directions for research and development in this rapidly growing field.

Keywords: Artificial Intelligence, Machine Learning, Prosthodontics, CAD/CAM

INTRODUCTION

The application of Artificial Intelligence (AI) and Machine Learning (ML) is revolutionizing healthcare, including dental specialties such as prosthodontics (1). Prosthodontics focuses on restoring oral function, comfort, appearance, and health through dental prostheses. As AI and ML continue to evolve, they are offering unprecedented improvements in areas like diagnosis, treatment planning, and the customization of dental prostheses (2). This review explores the impact of these technologies on prosthodontics and outlines their current and potential future applications.

Current Applications of AI in Prosthodontics

1. Diagnosis and Treatment Planning

AI and ML have significantly enhanced diagnostic and treatment planning capabilities in prosthodontics by offering more accurate, faster, and efficient analysis of clinical data. AI-powered systems can interpret vast amounts of data from various sources such as radiographs, cone-beam computed tomography (CBCT) scans, intraoral images, and patient medical histories. Convolutional neural networks (CNNs) and deep learning models are now capable of diagnosing oral diseases such as dental caries, periodontal diseases, and oral cancer with accuracy rates comparable to or exceeding experienced clinicians (3).

The implementation of AI in diagnosis goes beyond disease identification. Advanced AI algorithms are now analyzing structural characteristics of the oral cavity, such as tooth morphology, bone density, and soft tissue quality, allowing for highly personalized treatment plans. AI tools can integrate patient-specific variables, including occlusion patterns, oral hygiene status, and lifestyle factors, to provide comprehensive, individualized recommendations for prosthodontic treatment. The precision of AI-assisted diagnostics aids clinicians in managing complex cases, reducing diagnostic errors, and providing quicker and more accurate treatment planning (4).

For example, AI-based software can analyze patient radiographs to determine the most appropriate approach to treat cases involving full-mouth rehabilitation. It can also predict potential complications before the treatment even begins, such as insufficient bone quality for implant placement. By combining clinical

experience with the power of AI, prosthodontists are now able to optimize treatment outcomes for their patients (5).

2. Computer-Aided Design and Manufacturing (CAD/CAM)

AI-driven CAD/CAM systems are revolutionizing prosthodontics by enabling faster, more accurate design and manufacturing of dental prostheses. Machine learning algorithms analyze thousands of previous successful prosthetic designs, and apply this data to create customized crowns, bridges, inlays, and dentures. These AI-driven systems learn from extensive datasets and are capable of automating the design process, ensuring precision in both fit and esthetics.

[figure 1] One of the key advancements in AI-enhanced CAD/CAM systems is their ability to simulate various functional stresses on dental restorations. These systems can predict how different prosthetic materials will respond to specific loading conditions, such as masticatory forces, over time. This virtual testing allows clinicians to choose materials and designs that will maximize both durability and patient comfort (6).

Furthermore, AI-integrated CAD/CAM platforms are able to personalize prosthetic design based on patient-specific anatomical structures, including teeth alignment, occlusion, and bone density. This level of customization reduces the need for post-manufacture adjustments, improving both the function and esthetic outcomes for patients. AI also helps select optimal materials based on clinical factors like occlusal forces, thereby minimizing the risk of prosthetic fractures or wear over time (7).

For example, AI-powered systems can generate multiple prosthesis designs for the same patient, allowing the clinician to choose the best option based on specific criteria like esthetics, material strength, or ease of fabrication. This innovation streamlines the workflow and minimizes errors that often arise in traditional manual CAD/CAM systems (8).

3. Digital Smile Design

Digital Smile Design (DSD) is another area where AI is making significant strides. AI-powered software is capable of generating detailed and accurate digital smile designs based on a patient's facial features, dental proportions, and esthetic preferences. AI technologies, such as facial recognition algorithms, are now being used to analyze a patient's facial dynamics, ensuring that the final design not only fits their teeth but also harmonizes with their entire face. [figure 2]

Recent developments in AI-powered DSD include emotion analysis software, which predicts how different smile designs will affect a patient's overall appearance and facial expressions. These systems can take into account dynamic factors, such as lip movement and facial muscle engagement, to simulate a more realistic final outcome. Additionally, AI-based DSD tools can generate 3D simulations of post-treatment results, allowing patients to visualize their new smile before the actual procedure (9).

This advancement enables better communication between the patient and clinician, improving patient satisfaction and reducing the need for post-treatment adjustments. Moreover, AI-powered DSD tools provide prosthodontists with multiple design options, each optimized for esthetics, durability, or patient preference. This personalized approach allows for more predictable treatment outcomes and a higher level of patient engagement (10).

4. Occlusion Analysis and Adjustment

Occlusion analysis is crucial in prosthodontics, as it affects the long-term success of restorations. AI and ML are enhancing occlusal analysis by processing large datasets from digital articulation systems and real-time 3D jaw movement records. By analyzing occlusal contacts and jaw movements, AI systems can suggest optimal occlusal schemes tailored to each patient [figure3].

AI-powered occlusion analysis tools now integrate data from digital impressions and articulation simulations to create a more comprehensive view of how a patient’s teeth will interact under functional load. These tools can simulate various jaw movements during activities such as chewing, speaking, and grinding, identifying areas where prosthetic designs may cause occlusal interferences or discomfort (11).

In complex prosthetic cases, such as full-mouth rehabilitations, AI-based occlusal analysis systems can dynamically adjust the occlusion design to minimize occlusal discrepancies and reduce the risk of long-term issues like bruxism or temporomandibular joint (TMJ) dysfunction. These adjustments are based on a thorough analysis of real-time data and patient-specific parameters (12).

AI’s role in occlusion extends beyond static analysis. Advanced systems are now capable of predicting how the occlusion will evolve over time as the patient’s prosthesis undergoes wear and tear. This predictive

capability allows prosthodontists to design prostheses that maintain optimal function for a longer duration, reducing the need for frequent adjustments.

5. Predictive Maintenance and Longevity

AI models are being developed to predict the longevity and potential failure points of dental prostheses, enabling clinicians to plan for maintenance before issues arise. These models use data from a variety of sources, including long-term clinical studies, patient-specific factors such as oral hygiene habits, and material science research, to provide insights into prosthetic durability.

AI algorithms can predict when a prosthesis is likely to fail due to factors such as wear patterns, occlusal forces, or material degradation. This enables prosthodontists to create personalized maintenance schedules, ensuring that interventions are made before complications arise, thus extending the lifespan of restorations (13). Predictive AI systems are becoming increasingly sophisticated, capable of incorporating not only clinical data but also patient-specific lifestyle factors like diet, oral hygiene habits, and stress levels, which affect the wear and longevity of prosthetic devices. By using these predictive insights, prosthodontists can tailor prosthesis designs and maintenance protocols to individual patients, ensuring longer-lasting restorations and minimizing the need for costly, time-consuming repairs or replacements (14).

6. Virtual Reality (VR) and Augmented Reality (AR) in Education and Training

AI-enhanced VR and AR platforms are becoming a valuable tool in prosthodontic education and training. These technologies provide immersive, interactive simulations that allow students and professionals to practice complex prosthetic procedures in a controlled, risk-free virtual environment. AI-driven adaptive learning systems identify a learner's strengths and weaknesses and tailor the educational content accordingly.[figure 4]

AI-powered VR systems can simulate real-life prosthodontic scenarios, enabling students to practice procedures such as dental implant placements or full-mouth rehabilitations. These virtual simulations can mimic various clinical challenges that would be difficult to replicate in traditional educational settings. Additionally, AI algorithms analyze student performance in real-time, offering personalized feedback and suggesting additional practice in areas where improvement is needed (15).

Moreover, AI-enhanced AR systems can overlay digital information onto a physical object, such as a patient's dental model or prosthesis. This allows students and clinicians to visualize anatomical structures and prosthetic designs more clearly, making it easier to plan and execute treatments (16). The integration of AI with AR enables a more interactive, hands-on approach to learning, improving both competence and confidence in clinical practice.

7. Patient Monitoring and Follow-up

AI-driven systems are transforming long-term patient monitoring by analyzing data from various sources, such as intraoral scanners, digital photographs, and wearable dental devices. AI algorithms can detect early signs of prosthetic failure, gum recession, or other complications, allowing for timely interventions and personalized follow-up care (17).

For example, machine learning models can analyze patient data over time to identify trends that indicate a developing problem, such as the loosening of an implant or the wear of a dental crown. These systems can then suggest a course of action, such as adjusting a patient's oral hygiene routine or scheduling a follow-up visit for further evaluation (18).

In addition to monitoring physical aspects of the prosthesis, AI is also being used to integrate patient-reported outcomes into the follow-up process. This includes data from smart dental devices, which can monitor habits like bruxism, or feedback from patients regarding comfort and function. AI-powered systems analyze this data to create a more comprehensive view of the prosthesis' performance, helping prosthodontists provide more personalized care and improve long-term patient satisfaction.

8. AI in Implantology

AI is also transforming implantology within prosthodontics. AI algorithms are used in surgical planning for dental implants by analyzing CBCT (Cone Beam Computed Tomography) scans to determine optimal implant placement (19). These systems consider factors such as bone density, anatomical structures, and occlusal forces to recommend ideal implant positions, improving success rates and reducing complications.[figure 5]

Example: AI can predict the stability of dental implants post-surgery by analyzing factors such as bone density, implant surface characteristics, and patient medical history (20).

9. Machine Learning in Predicting Treatment Outcomes

Machine Learning (ML) models are being developed to predict the success and longevity of prosthetic treatments based on patient history, occlusal schemes, and previous treatment data (21). These models provide prosthodontists with tools to estimate treatment outcomes more accurately, allowing for better patient prognoses and personalized treatment approaches.[figure 6]

Example: A prosthodontist can input various patient-specific parameters, such as bone density and bite force, into an AI system to receive a prediction on the likelihood of long-term success for a full-mouth rehabilitation.

Benefits of AI in Prosthodontics

1. Enhanced Accuracy

AI-driven diagnostic tools offer significantly higher accuracy compared to traditional diagnostic methods. By analyzing complex imaging data and recognizing patterns that may be missed by the human eye, AI provides precise diagnostic and treatment solutions.

2. Increased Efficiency

AI helps streamline clinical workflows by automating time-consuming tasks such as data analysis, prosthesis design, and treatment planning. This enables prosthodontists to focus on patient care while AI handles the computational and repetitive aspects.

3. Customization of Treatment

AI systems can tailor treatments to each patient's unique anatomical and functional needs, optimizing the fit and function of prostheses. By customizing each stage, from diagnosis to prosthetic design, AI enhances both functional and esthetic outcomes.

4. Cost-Effectiveness

While initial AI adoption may be costly, the long-term savings come from reduced treatment errors, fewer adjustments or remakes of prostheses, and decreased treatment times.

Challenges and Limitations of AI in Prosthodontics

1. Data Quality and Availability

AI models require high-quality, extensive datasets for training, which can be a challenge in dentistry due to the lack of standardized, large-scale datasets. Variability in data from different clinics and geographic regions can affect the performance and generalizability of AI models.

2. Cost of Implementation

The integration of AI systems into dental practices involves significant financial investment. Advanced software, hardware, and training resources may not be accessible to all prosthodontists, particularly in smaller practices or developing regions.

3. Ethical Concerns

AI applications raise several ethical issues, such as patient data privacy and the potential for over-reliance on AI. Furthermore, concerns about AI taking over clinical decision-making pose challenges regarding the extent to which technology should influence patient care.

4. Training and Education

For AI systems to be fully integrated into clinical practice, prosthodontists must receive proper training. Understanding how to operate and interpret AI systems is crucial to avoid potential misdiagnoses or errors in treatment planning.

Future Directions for AI in Prosthodontics

1. Deep Learning and Neural Networks

The development of deep learning models, specifically neural networks, is expected to further enhance diagnostic and treatment capabilities in prosthodontics. These systems can learn from vast amounts of data, refining their accuracy over time.

2. AI-Driven Robotic Assistance

AI and robotics could soon be used in prosthodontic surgeries, such as implant placement, allowing for enhanced precision and minimizing human error. AI-guided robotic systems could be especially useful in complex, high-risk procedures.

3. AI in Digital Prosthodontics

The future of prosthodontics lies in fully digital workflows, where AI will optimize every step, from diagnosis to final restoration. The seamless integration of AI with 3D printing technologies will enable faster, more accurate prostheses, offering patients superior outcomes.

4. AI for Geriatric Prosthodontics

The growing elderly population presents unique challenges for prosthodontic care. AI can help manage these complex cases by analyzing systemic and oral health factors to recommend treatments tailored to geriatric patients.

CONCLUSION

AI and machine learning technologies are poised to revolutionize prosthodontics by enhancing diagnostic accuracy, optimizing treatment planning, improving prosthesis design, and transforming implantology. While challenges related to data quality, implementation costs, and ethical considerations remain, the potential benefits of AI in prosthodontics are vast. As AI technology continues to evolve, it is expected to become a central component of modern dental restoration practices, offering significant improvements in clinical outcomes and patient care.

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CONFLICT OF INTEREST: The author declares that there is no conflict of interest regarding the publication of this review article.

FIGURES

FIGURE 1

Figure 2

Figure 3

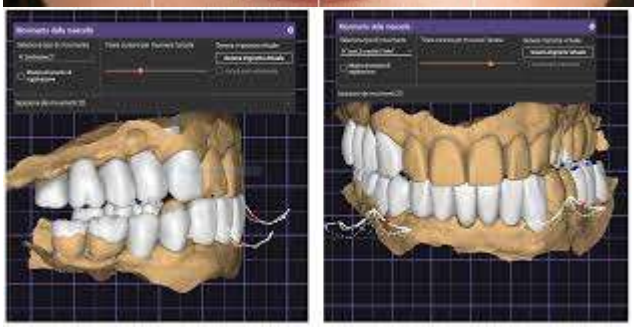

Figure 4

Figure 5

Figure 6