Review article

Revolutionizing Smiles: AI-Driven Innovation in Prosthodontics

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Abstract

This review article presents an overview of recent advancements and challenges in the integration of technology within prosthodontics. Prosthodontics, a dental specialty focused on the restoration and replacement of teeth, encompasses the planning and execution of treatments. The article examines the latest developments in removable dentures, including innovations in their design and manufacturing processes. In addition, it explores the role of artificial intelligence (AI) in maxillofacial treatments within the field of prosthetics. The review also addresses the concept of individualized cognitive models in prosthetics, particularly in the context of personalized care. By synthesizing existing literature on AI in prosthetics, the article offers insights into current applications, ongoing challenges, and potential future directions.

Keywords: 3D printing in prosthodontics, Artificial intelligence-assisted design, Artificial intelligence-enhanced patient monitoring, Artificial intelligence-powered treatment planning, Data-driven prosthetic solutions, Digital prosthodontics.

Introduction

Digitalization is rapidly expanding, making life easier by enabling smarter work rather than harder work. These advancements have significantly enhanced the quality of dental treatments.[1] While the application of artificial intelligence (AI) in dentistry is still in its early stages, it follows similar trends seen in other fields. AI helps reduce the workload in dentistry, with its applications spanning four key areas: Diagnosis, decision-making, treatment planning, and prognosis. AI's improved accuracy and precision have garnered significant attention and are widely applied in various areas of dentistry. In addition, there is a growing expertise in dental machine systems.[2] In prosthodontics, AI is applied in areas such as fixed prostheses, removable prostheses, implantology, esthetic dentistry, and computer-aided design and computer-aided manufacturing (CAD/CAM) systems. It simplifies complex dental procedures, such as assessing bone density and vital structures for implant placement, leading to more accurate planning and higher success rates. Ongoing research continues to expand the role of AI in dental care. This study aims to summarize the use of AI in prosthodontics, offering valuable insights for future researchers and dental practitioners interested in exploring AI's potential in this field.[3]

History of AI

AI has been in development since the 1950s when Alan Turing proposed that machines could think like humans. To test this concept, Turing introduced the Turing Test, in which a human observer tries to distinguish between communication from a human and that from a machine. If the observer cannot tell the difference, the machine is considered to exhibit "machine intelligence."[4] AI was formally introduced at a conference in 1955, but due to technological limitations, scientists were unable to create truly intelligent machines at that time. From 1957 to 1974, as computer power and accessibility grew, so did the field of AI. However, the field experienced two periods of stagnation, known as "intellectual winters," caused by underutilization and declining research funding. In the 1980s, AI progressed through developments in machine learning. Key milestones in the field of computer science occurred in 2012 and 2017. Notable AI examples include Deep Blue and AlphaGo. More recently, OpenAI introduced ChatGPT, a text generation model capable of producing human-like responses based on text input.

Applications of AI in Prosthodontics

AI and removable partial denture (RPD)

Using AI in the creation of 3D-printed partial dentures (RPD) offers a more accurate method compared to traditional

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techniques. AI algorithms can analyze patient data to generate personalized and customized RPD designs.[5] Furthermore, AI can assist in evaluating the fit and function of the RPD through computer-aided analysis, ensuring precise measurements and assessments of joints, occlusion, and overall function. This can lead to improved patient satisfaction and better treatment outcomes. In conclusion, AI has the potential to enhance both the design and manufacturing processes of RPDs, offering more effective treatments for partially edentulous patients.[6]

AI and Fixed Prosthodontics

In fixed prosthodontics, AI works seamlessly with CAD/CAM systems to automate the design and milling of restorations such as crowns and bridges. AI models can effectively interpret digital impressions and radiographs, recommending the best materials and designs while also predicting the long-term durability of the prosthetics.[7] Notably, AI Automate and AI Dentbird by 3Shape Dental System are recognized for their precision in evaluating crown preparation margins and minimizing occlusal and positional errors, which ultimately enhances the success rate of fixed restorations. The application of expertise in permanent restorations can enhance the accuracy and functionality of tooth preparations.[8] AI algorithms can analyze and learn from a vast library of completed designs to gain insights into the appearance, continuity, and contours around teeth for each case. In addition, AI can assist in the tooth preparation process by accurately guiding the placement of cuts and lines, tasks that typically require significant skill and time. A study by Zhang *et al*.[10] demonstrated the potential of AI in this area, using a deep learning model called Sparse Octree, a convolutional neural network, to extract edges with high precision, achieving an impressive 97.43% accuracy. These findings underscore the potential of AI to improve the accuracy and efficiency of tooth preparation in permanent restorations.

AI and Maxillofacial Prosthetics

AI is increasingly being utilized in maxillofacial prosthetics to assist patients with deformities or injuries caused by trauma or congenital conditions in restoring both function and appearance. AI-supported prosthetic devices, such as prosthetic eyes and smart reading glasses, offer solutions for patients who may not require surgery.[10] For individuals with disabilities, including those who are visually impaired or have normal vision, smart bionic prosthetic eyes[11] can read, recognize text, identify faces, and record audio. In addition, RaPiD, a design assistant, combines anthropological data and patient preferences to recommend the most suitable prosthesis, ensuring both functional and esthetic results.

In addition, AI techniques are being applied in tissue engineering to create skin grafts, which can serve as temporary wound protection or provide long-term skin replacement, promoting faster healing and reducing the risk of infection.[12] Another emerging application of AI is in artificial olfaction, where AI systems mimic the human olfactory system using electrical signals. These systems can be employed for a variety of purposes, including disease detection, environmental monitoring, public safety, and applications in the food and agriculture industries. AI-powered 3D printing and facial recognition technologies enable clinicians to create highly personalized prosthetics.

AI and Implant Dentistry

AI is transforming the field of dental implants by enhancing the precision and efficiency of implant placement, planning, and overall treatment outcomes. Through various AI technologies, the process of dental implantology has become more personalized, accurate, and data-driven. AI algorithms analyze cone beam computed tomography (CBCT) images to create 3D models of the patient's jaw structure.[13] These detailed models allow dental professionals to better visualize the bone's quality and quantity, both crucial factors in ensuring the success of dental implants. AI can recommend optimal placement sites for implants, taking into account anatomical considerations and minimizing risks during surgery. Assess bone density and structure to predict the best locations for implants. This analysis helps determine if bone grafts or other procedures are necessary before implant placement, improving overall treatment outcomes. It can identify patients who may be at risk for implant failure, enabling dental professionals to take proactive measures. This predictive ability improves the overall success rates of dental implants.[14] Beyond implant placement, AI plays a role in designing and producing prostheses (the artificial teeth that are placed on implants). AI-powered software helps create highly accurate, custom-designed prostheses that fit seamlessly with the patient's natural dental structure, enhancing both function and esthetics.

AI and CAD/CAM

The integration of AI with CAD/CAM technology has significantly advanced modern dentistry. These technologies together streamline the process of dental restoration, enhancing precision, efficiency, and patient satisfaction.[15] Here is how AI and CAD/CAM are shaping the future of dentistry. It helps in analyzing diagnostic images, such as X-rays and CBCT scans, to assess a patient's dental conditions. AI algorithms can detect issues such as cavities, cracks, and gum disease that may be invisible to the human eye. It also enhances the CAD/CAM process by offering smarter designs, predicting the best materials, and ensuring the final restoration fits perfectly with the patient's natural dental anatomy. AI can also optimize the design of restorations based on factors such as the patient's bite and tooth movement, ensuring better long-term outcomes.[16] AI minimizes human error during the design and manufacturing processes. By automating the design process and improving the accuracy of digital impressions, the likelihood of making mistakes is significantly reduced.

AI and Esthetic Dentistry

AI is increasingly influencing the field of esthetic dentistry, enabling practitioners to achieve more precise, personalized, and efficient outcomes for patients seeking cosmetic improvements. By integrating AI into various aspects of esthetic dentistry, dentists can enhance the quality of care, streamline procedures, and deliver results that better align with the patient's desired esthetic goals. Here is how AI is enhancing esthetics in dentistry.[17] AI-powered software allows dentists to create customized smile designs that are tailored to the patient's unique facial features, preferences, and personality. Through digital imaging and facial recognition, AI can analyze the patient's facial structure, skin tone, and symmetry, helping to design a smile that harmonizes with their overall appearance. One of the most significant advancements in esthetic dentistry is the ability to virtually simulate smile outcomes before any physical changes are made.[18] AI allows patients to visualize the potential results of various treatments, such as veneers, crowns, or orthodontic procedures, in real-time. This simulation provides a clear preview, helping both the patient and the dentist make informed decisions about the treatment plan, improving satisfaction, and setting realistic expectations.

Discussion

The success of AI has demonstrated its ability to surpass human intelligence in certain areas, but its development relies heavily on software, hardware, and data input. Tasks involving 3D models, for example, require powerful computational training algorithms.[19] Modeling and representing 3D data are often used to mitigate computational challenges and preserve details during conversion. The advancement of AI applications is largely dependent on the quality of AI algorithms, computational power, and access to digital learning materials.

Evidence-based dentistry (EBD) is an approach to oral care that integrates clinical evaluation of scientific evidence with the needs and preferences of practitioners, dental professionals, and patients.[20] Both EBD and evidence-based medicine are considered the gold standard for decision-making by health-care professionals. Machine learning models can assist health-care providers by storing and analyzing ongoing medical and patient-related information. However, processing medical records is complex because diagnoses often rely on multiple sources of data. Challenges such as data privacy concerns, organizational barriers, and disparate systems make it difficult to integrate and process medical records effectively.[21]

Due to the complexity, sensitivity, and limitations of using dental and medical data for machine learning, attention must be paid to how data is handled. At present, many AI-based medical solutions produce results that only show a subset of decisions required for clinical use, making them challenging to implement.[22] While EBD is more intuitive and transparent – decisions are made by integrating various sources to minimize bias – machine learning is often seen as a "black box" due to its inability to clearly explain how certain results are achieved.[23] This lack of transparency can cause hesitation among some health-care providers.

Machine learning is a relatively new medical tool that enhances diagnoses by identifying patterns in medical records. Although it can derive insights from various data types, existing machine learning applications often rely on similar datasets for diagnosis.[24] The addition of machine learning to EBD could improve the identification of clinical and disease-related information, potentially leading to more accurate self-diagnosis. EBD and machine learning are interdependent techniques that, when combined, can offer better outcomes for clinicians and patients alike.[25]

Conclusion

AI is significantly transforming prosthodontics by improving diagnosis, treatment planning, design, manufacturing, and long-term monitoring of prosthetic devices. With the ability to create personalized treatment plans, enhance the accuracy of implant placement, optimize the design of crowns and dentures, and reduce human error, AI is revolutionizing the way prosthodontic treatments are delivered. As AI continues to advance, it will likely play an even more critical role in enhancing patient outcomes, improving efficiency, and reducing treatment times in prosthodontics. The future of prosthodontics lies in the continued integration of AI and digital technologies, which promise to further elevate the field and provide patients with superior, personalized care.

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