

ROLE OF ARTIFICIAL INTELLIGENCE IN PROSTHODONTICS TO ASSESS ITS EFFECTIVENESS AND SUCCESS: A SYSTEMATIC REVIEW

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ABSTRACT

Prosthodontics, a discipline including both art and science, is dedicated to the comprehensive management of patients with dental conditions due to the absence or inadequacy of teeth, as well as oral and maxillofacial tissues. Its core objectives are diagnosis, strategic planning, rehabilitation, and maintenance of patients' functional, comfortable, and healthy oral states. The major approach used for the treatment of this condition is prosthesis replacement. Prosthodontics primarily focuses on the management and fabrication of fixed and removable dental prostheses, alongside implant surgery, the development of maxillofacial prostheses, and the enhancement of finishing margins adjacent to the tooth to optimize the extension and fit of the prosthesis. Additionally, it is used to preserve the maxillomandibular connection and determine the suitable tooth shade for aesthetic purposes.

AI is increasingly being used in the field of prosthodontics, leading to advancements in the rehabilitation of persons requiring prosthodontic therapy. AI offers significant advantages in the fields of removable, fixed, maxillofacial, and implant prosthodontics. The use of AI enhances the efficacy and acceptance of prosthodontic treatment, while concurrently reducing the probability of human errors. Furthermore, it has been shown that the field of prosthodontic implant applications derives the most benefit from AI. Researchers have also been found to use AI in the development of dental and overall healthcare solutions.

Key words: Artificial intelligence, Prosthodontics, Digital dentistry, Systematic review.

Introduction

The use of AI in dentistry is now in its nascent stages, mirroring its implementation in other domains. There are four distinct domains in which AI is used within the field of dentistry. These areas include diagnostics, decision-making, treatment planning, and prediction of treatment outcomes. The primary use of artificial intelligence in dentistry that garners significant attention is its utilization in the field of diagnostics. The integration of AI into dental practice has the potential to alleviate the workload of dentists by enhancing the accuracy and precision of diagnosis. On the one hand, it is seen that dentists are progressively using computer technology to inform their decision-making processes [1, 2].

Nevertheless, there is a growing trend towards increased intelligence, accuracy, and reliability in dental computer systems. Research in the subject of AI is now being undertaken across several domains within the discipline of dentistry. The evaluation of the model's performance, including metrics such as accuracy, sensitivity, specificity, F1 score, and AUC area, is crucial. Additionally, it is important to consider the distribution of data throughout the training, test, and validation sets. Lastly, the study strategy should be carefully considered. Comparing memory performance across several published research on dental AI

under the receiver operating characteristic (ROC) Curve remains challenging. The content, as mentioned earlier, was only partially addressed in the majority of the publications. The development of the MICLAIM checklist has been undertaken to achieve comparable levels of transparency and utility in the use of AI within the field of medicine.

The role of artificial intelligence in prosthodontics

Prosthodontics, a discipline encompassing the art and science of dentistry, is dedicated to the examination, analysis, strategic intervention, and maintenance of patients' oral and maxillofacial structures, with a particular emphasis on addressing conditions arising from the absence or inadequacy of teeth and associated tissues. The major approach used for the treatment of this condition is prosthesis replacement [3]. The primary focus of prosthodontics revolves around the management and fabrication of fixed and removable dental prostheses. Additionally, it encompasses implant surgery, the development of maxillofacial prostheses, and the meticulous preparation of finishing margins adjacent to the tooth to enhance the extension and fitting of the prosthesis. Additionally, it serves the purpose of preserving the maxillomandibular connection and determining the suitable tooth shade for aesthetic purposes [4].

Application of AI in prosthodontics

AI simulates human thought and behavior using machine-learning algorithms. This model was trained using previously acquired data and is based on the statistical analysis of historical data. The exponential growth of digital data allows AI systems to be trained to provide increasingly accurate findings. Fundamental changes were seen in using artificial intelligence-based technologies for automated diagnosis, predictive assessments, and categorization or diagnostic tools. In prosthodontics, all facets of contemporary dental technology are used. The more conventional ways of taking imprints were replaced with digital ones using an intraoral scanner. When just one crown or a short-span FPD has to be created, intraoral scanners are trustworthy enough to be used regularly. However, developments in the scanning industry allowed for its application in maxillofacial intraoral scans and the manufacturing of entire dentures [5-7].

The artificial intelligence system successfully achieved margin detection after an intraoral scan in the field of fixed prosthodontics. CAD/CAM, an acronym for "computer-aided design/computer-aided manufacturing," is used in the fabrication of both fixed and detachable dental prostheses. This methodology has the potential to provide optimal crown designs for many scenarios by using data obtained from several natural crowns.

In recent times, there has been widespread use of digital technology in the field of dentistry, intending to aid patients in achieving the aesthetically pleasing mouths they have long aspired for. Any therapeutic intervention that modifies a patient's smile is rooted in the virtual representation of their anatomical structure. The technologies included in this category consist of 3D face tracking and cost-effective virtual 3D data hybrids, such as fragmented cone beam computed tomography (CBCT), intraoral scans, and face scans. The early grin designs were constructed using simple sheet drawings derived from two-dimensional printed photographs of patients [8, 9].

The use of AI in the field of implant prosthodontics

In the field of prosthodontics, both the patient and the dentist need to adhere to the utmost standards of prosthesis. The production of a faultless output requires a significant allocation of labor and money; nonetheless, there are instances where more enhancements are required. The integration of a designing and producing unit inside a computer system enables the customization of medical devices according to a patient's preferences, leading to time and resource efficiency. When evaluating aesthetics, an extensive understanding of dental anatomy is often taken into account. This was juxtaposed with the use of a traditional framework. The optimal approach for dental implant therapy involves the integration of cone beam computed tomography (CBCT) and intraoral scanning techniques. The integration of AI in the field of implant dentistry offers the potential to merge these two domains and develop advanced prosthetic solutions for the future.

The main areas of emphasis in the field of prosthodontics encompass the management of temporary and removable dental prostheses, the development of precise margins adjacent to the teeth to enhance the durability and alignment of the prosthesis, the practice of implant surgery, the fabrication of maxillofacial prostheses, the maintenance of optimal maxillo-mandibular relationships, and the selection of teeth color to enhance aesthetic appeal [10].

AI and computer-aided design/computer-aided manufacturing (CAD/CAM)

In the field of prosthodontics, there is a shared expectation among patients and healthcare professionals for the provision of prostheses that exhibit a high level of quality. Achieving optimal outcomes requires the involvement of several individuals and a substantial allocation of resources. The use of computers' inherent design and manufacturing skills enables the development and fabrication of personalized medical prostheses for individuals. This may be achieved via many methods, such as design, milling, or printing. The availability of fresh prosthetic examples often shared on the internet renders the capacity of AI to evaluate and interpret prostheses within the database a significant advantage. The analysis of dental anatomy data was conducted to assess aesthetic aspects [11].

The topic of interest is the field of maxillofacial prosthetics and its intersection with AI.

Convolutional neural networks (CNNs), which exhibit structural similarities to biological neurons, are used in the field of AI. The artificial ocular prosthesis, which was created in the United States, has been successfully used by a cohort of twelve patients with visual impairments. AI-powered technologies have the potential to enhance visual capabilities without the need for surgical intervention. Dental practitioners can use AI and specialized design tools to create aesthetically pleasing prostheses for patients. This process involves considering anthropological calculations, facial proportions, ethnic considerations, and the preferences expressed by the individual patient. Smart reading glasses are accessible to anyone, visually impaired or blind. The equipment in question is an innovative voice-activated apparatus that can be affixed to a wide range of eyewear. The primary objective of this technology is to provide support and aid to those who have blindness or visual impairment. The device can instantly scan and interpret text from many sources, such as books and smartphone screens, as well as other surfaces. Additionally, it demonstrates the ability to identify and distinguish faces, enhancing its overall efficiency. Furthermore, it facilitates an independent lifestyle for its users [12].

The topic of AI ethics has gained significant attention in academic and professional circles.

To uphold the ethical standards of computer systems, AI development needs to prioritize the prevention of damage

to human beings. The use of AI inside clinical environments has considerable potential for enhancing healthcare outcomes. However, this advancement also presents notable ethical concerns that need resolution. Several prominent IT groups in the present day advocate for the broader use of AI. Before the actualization of this concept, it is essential to examine and evaluate several ethical and risk assessment concerns thoroughly. To effectively harness AI within the healthcare sector, it is imperative to address four fundamental ethical concerns: data privacy, informed consent pertaining to data use, safety, and transparency, as well as algorithmic fairness and the mitigation of biases. The use of AI may impede our ability to assign responsibility for any inflicted harm. The potential impact of machines on the human capacity to attribute blame and assume accountability for our acts remains undetermined but significant. To ensure the protection of patients and effectively navigate a dynamic and often disruptive healthcare landscape, AI in healthcare must adhere to ethical principles [13].

The prospects

The confirmation of the generalizability and reliability of the AI models provided remains essential, necessitating the use of adequate external data sourced from freshly recruited patients or acquired from other dental establishments. One of the enduring goals in the field of AI research in dentistry is to enhance AI models to the extent that they possess the capability to detect incipient issues that are imperceptible to

the unassisted human eye. The use of CAD/CAM technology and the growing requirement for enhanced accuracy in prosthodontic implant procedures necessitates the integration of AI-enabled algorithms. Explainability may be evaluated at all stages of AI development, including pre-modeling, model creation, and post-modeling [14].

Materials and Methods

Using the databases PubMed, Medline, and ScienceDirect, a comprehensive evaluation of the literature from 2015 to 2023 was conducted. The keywords used were "Artificial intelligence", "prosthodontics", and "digital dentistry." The method of selecting the articles that were searched for was shown in a PRISMA flowchart (**Figure 1**).

The following requirements must be met for inclusion:

- Case-control and randomized control studies.
- Published in English between 2015 and 2023
- In vivo (humans).

Exclusion criteria

- Outside of the designated period.
- Language other than English.
- In vitro.
- systematic research, meta-analyses, opinions of specialists, or narrative reviews.

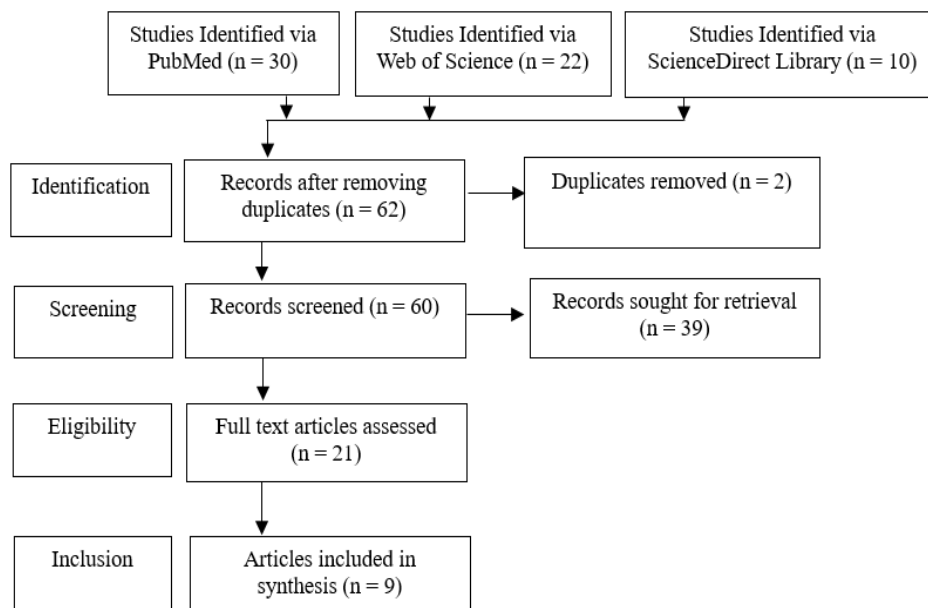


Figure 1. PRISMA Flow Diagram

Risk of bias assessment

The efficacy of the included studies was evaluated using the Cochrane risk of bias assessment technique (**Table 1**).

Table 1. Summary of Cochrane Risk of Bias Assessment

Study	Selection Bias/Appropriate control selection/baseline characteristics similarity	Selection bias in randomization	Selection bias in allocation concealment	Performance-related bias in blinding	Reporting bias/Selective reporting of outcomes	Detection bias Blinding outcome assessors	Accounting for confounding bias
Revilla-León <i>et al.</i> (2021) [13]	+	+	+	+	-	+	+
Pareek <i>et al.</i> (2022) [14]	+	-	+	+	+	+	+
Sikri <i>et al.</i> (2023) [15]	+	+	+	+	+	+	+
Singi <i>et al.</i> (2022) [16]	+	+	-	+	+	+	+
Shree <i>et al.</i> (2023) [17]	+	-	+	+	+	+	+
Shajahan <i>et al.</i> (2021) [18]	+	+	+	+	+	+	-
Alshadidi <i>et al.</i> (2023) [19]	+	+	+	+	+	+	-
Moshree <i>et al.</i> (2022) [20]	+	+	-	+	+	+	+
Singi <i>et al.</i> (2022) [16]	+	+	+	+	+	+	+

Results and Discussion

The use of artificial intelligence in the field of prosthodontics is seeing a notable development. Nevertheless, there is a need for enhanced documentation and analysis of the current status of artificial intelligence in prosthodontic applications. The primary objective of this systematic study was to assess the effectiveness of artificial intelligence models in the field of prosthodontics. The approach used in this study was the examination and categorization of a total of thirty-six articles, which were then classified into six distinct groups. One scholarly article examined the development of an AI model to select tooth hues. The study found that this AI model demonstrated improved accuracy in shade matching compared to standard visual selection methods (**Table 2**).

Additionally, nine papers explored the feasibility of using different AI models to automate the design of dental restorations. One artificial intelligence model demonstrated a mean accuracy ranging from 90.6% to 97.4% in autonomously marking the margin line. Two studies were conducted to develop artificial intelligence algorithms aimed at enhancing the manufacturing casting process. These studies reported improvements in the design process, a reduction in the porosity of the cast metal, and an overall reduction in manufacturing time. Additionally, a study proposed an artificial intelligence model capable of predicting facial expressions.

Pareek *et al.* (2022) conducted a comprehensive analysis to examine the prominent disruptive technology of the current period, namely AI [14]. AI is already driving significant transformations across several industries, ranging from dentistry to space exploration. Biomedicine has several advantages in contrast to conventional methods of diagnosis, treatment planning, patient recording, and

management. AI is widely used across several industries aimed at enhancing the quality of life for both patients and medical practitioners. The present research conducted a comprehensive examination of the use of AI in the field of prosthodontics. Prosthetic dentistry, sometimes referred to as prosthodontics, is a dental specialty that primarily concerns itself with the restoration and rehabilitation of missing teeth by the use of implants, permanent and removable prostheses, or other biocompatible substitutes. Furthermore, it facilitates the restoration of the oral cavity's healthy soft and hard tissues, therefore improving the overall state of the oral cavity. The subsequent analysis underscored the efficacy of contemporary AI in the realm of dental prostheses, particularly in terms of its diagnostic capabilities and the production of prostheses that are tailored to individual patients.

In a study conducted by Sikri *et al.* (2023) [15], it was shown that AI is incapable of replacing dental surgeons due to the multifaceted nature of their job, which involves patient treatment, diagnosis, and the integration of findings with other clinical data. The convergence of artificial intelligence and digitalization has given rise to a new paradigm in the field of dentistry, presenting promising opportunities for future advancements. To address the primary obstacle to the use of AI, namely the availability of sufficient and accurate data, dental practitioners should prioritize the collection and entry of precise data into their database. This narrative review article examines the many uses of AI in the fields of prosthodontics and oral implantology. It also explores the current limitations of AI in these areas and discusses potential future applications. The primary focus is on using AI to diagnose problems and develop personalized prostheses for patients.

Singi *et al.* (2022) conducted a study that revealed that AI has the potential to enhance several aspects of oral healthcare practice, including patient recording, diagnosis,

treatment planning, and patient management. This technological advancement offers oral healthcare practitioners the opportunity to improve their efficiency and productivity, reducing the need for onerous manual processes. Although dentistry does not primarily focus on detecting illnesses, it does include integrating with other clinical findings and providing patient treatment, hence making it irreplaceable by technology. The integration of AI and digitalization has ushered in a new era in the field of dentistry, offering promising prospects for the future. The current limitation impeding the widespread use of AI is the need for enhanced data reliability and sufficiency. To effectively use AI in the field of dentistry, dental professionals and doctors should prioritize the collection and integration of credible data into their databases. The primary objective of this study is to examine a range of AI applications within the field of prosthodontics. It aims to identify the limitations associated with these applications and explore their potential for future advancements.

The objective of the research conducted by Shree *et al.* (2023) was to investigate the existing body of literature on the use of AI within the field of prosthodontics. The robotic system performs various tasks in the field of dentistry, including the alignment of teeth to create complete dentures, the assessment of facial changes resulting from prolonged use of complete dentures, the preparation of teeth for crown placement, the utilization of artificial intelligence models to identify and predict the success of different types of dental implants, the drilling of implant sites, and the assistance in designing removable partial dentures using Mac RPD technology. The use of AI within the field of dentistry has made significant progress. The majority of the studies included in this review had favorable results. The acquisition of a comprehensive understanding of AI concepts and procedures yields prospective advantages. Nevertheless, a significant limitation lies in the accessibility of comprehensive and accurate data.

According to the findings of Shajahan *et al.* (2021) [18], their study has shown that artificial intelligence has brought about substantial transformations in the fields of medicine and dentistry. While AI systems have shown to be valuable tools in the field of dentistry and dental education, it is important to acknowledge the intricate nature of the human biological system. It is crucial to recognize that these technical developments are ultimately the outcome of

human ingenuity and exploration. In addition, it is important to note that AI is unable to replace human knowledge, competence, or treatment planning. Rather, its role is limited to assisting physicians in the execution of their professional tasks.

In their study, Alshadidi *et al.* (2023) investigated the potential use of artificial intelligence in prosthodontics for issue identification and the development of patient-specific prostheses. A total of 172 dentistry publications relating to AI were discovered based on their titles and abstracts and then analyzed for this research. Thirty-eight papers were discarded. The study revealed a substantial increase in the use of AI in the field of prosthodontics. The data description presented an overview of the latest developments in the use of AI in the field of prosthodontics. It highlighted the utilization of AI in several areas, such as automated diagnostic generation, predictive analytics, and classification or verification tools. This was particularly noteworthy considering the extensive body of literature documenting the many applications of AI in this field.

Moshree *et al.* (2022) conducted a study including four research that examined neural network models. Among these investigations, one used a forecasting model, while another utilized an analytical CAD application equipped with AI and algorithms.

Singi *et al.* (2022) [16] determined in their review that every sector is being transformed by AI, from space exploration to dentistry. Biomedicine provides a variety of advantages over conventional diagnosis, treatment planning, patient recording, and management. Every business uses AI to simplify life for patients and medical staff. In the present paper, the use of AI in prosthodontics was reviewed. Robots, which save manual labor and increase the accuracy and precision of treatments, are gaining favor in various areas of prosthetic dentistry. The best human innovation ever is considered to be the robot. Initially, the primary uses of robots in prosthetic dentistry were manufacturing entire dentures and aiding dental implant procedures. However, as engineering and technology have advanced, so have their uses in prosthetic dentistry. In the intricate subject of prosthetic dentistry, this article provides a broad overview of the different uses of AI and robotics and their current state of development.

Table 2. Summarizes past studies on AI in Prosthodontics, including objectives, AI applications, findings, and limitations of AI in prosthodontics from past studies.

Author's name	Objectives	Applications of AI in Prosthodontics	Findings	Limitations of AI in Prosthodontics
Revilla-León <i>et al.</i> (2021) [13]	Assess the performance of AI models in prosthodontics	- Choosing the right tooth shade - Automating the design of restorations - Depicting the tooth preparation completion line - Improving casting production efficiency - Designing	- Better shade matching than conventional selection - Feasibility of automated restoration design - Accurate margin line marking - Improved manufacturing casting -	Limited study sample size

		removable partial dentures - Forecasting changes in facial features in detachable prosthesis	Predictive capability for facial changes - Development of clinical decision support systems	
Pareek <i>et al.</i> (2022) [14]	Review the implementation of AI in prosthodontics	- Diagnosis - Treatment planning - Patient documentation and management	Improved patient-specific prosthesis construction and diagnosis	None provided in the text
Sikri <i>et al.</i> (2023) [15]	Examine various uses of AI in prosthodontics	- Diagnosis - Patient-specific prostheses - Potential future applications	Integration of AI and digitization in dentistry	Need for accurate data collection for AI
Singi <i>et al.</i> (2022) [16]	Focus on applications of AI in prosthodontics	- Patient documentation - Diagnosis - Treatment planning - Patient management	Improved efficiency for oral healthcare professionals	Lack of accurate data as a barrier
Shree <i>et al.</i> (2023) [17]	Review AI applications in prosthodontics	- CAD-CAM dentures - Smile designing software - Tooth arrangement for complete dentures - Facial deformation prediction - Tooth preparation for crown placement - Implant type recognition - Implant success prediction - Robot for drilling implant site - Mac RPD design	Positive results for AI applications in the dental field	Mentioned the availability of insufficient and inaccurate details as a disadvantage
Shajahan <i>et al.</i> (2021) [18]	Discuss the impact of AI in medicine and dentistry	- General impact of AI in healthcare and dentistry	Acknowledgment of AI supporting clinicians but not replacing human knowledge and skills	None provided in the text
Alshadidi <i>et al.</i> (2023) [19]	Analyze AI use in prosthodontics	- Diagnosing abnormalities - Creating patient-specific prostheses	Significant increase in AI use in prosthodontics	Mentioned AI applications in diagnostics, prediction, and classification
Moshree <i>et al.</i> (2022) [20]	Examine AI models and their impact	- Impact of AI in prosthodontics - Use of neural network models, forecasting models, and CAD program algorithms	Steady progress in AI use in prosthodontics	Focus on CBCT and 3D scans for more accurate diagnosis
Singi <i>et al.</i> (2022) [16]	Review AI applications and robots in prosthetic dentistry	- Use of robots in prosthetic dentistry	Use of robots for various prosthetic dentistry applications	None provided in the text

This in-depth examination of AI applications in prosthodontics demonstrated the prediction ability and identification potential of AI for use in automated diagnostics. Due to the rapid advancement of digital technology in the preceding two to three years, the scope of this investigation was restricted to the past four years. Rather than offering a comprehensive overview of artificial intelligence in dentistry, the objective of this methodical study was to illustrate prosthetic AI applications. The findings demonstrated that CAD/CAM systems, implant prostheses, and orofacial anatomy investigations were among the prosthodontic applications of AI. The use of AI in prosthodontics was covered in only 24 eligible publications. While the field of artificial intelligence dental image analysis diagnosis has long focused on dynamic caries detection, it has recently expanded to other areas of interest, showcasing the use of AI technology in prosthodontics [21-24]. Prosthodontics is a large and complex area of dentistry; regular AI technology applications may be beneficial.

Eleven papers that assessed the feasibility of automating dental restorations using AI models to expedite CAD design processes and shorten production times were considered. Due to the need for partial input data from the images, such as onlay or inlay preparations, accurately replicating the original geometry, and reconstructing or estimating the anatomy of dental surfaces, particularly the occlusal surface, is a frequent problem [25]. The goal of the AI program is to provide a dental restorative design that can be produced using additive or subtractive methods. The research under review evaluated AI models for dental restorative design or CAD modeling. It is possible to separate two main categories: research and the development of algorithms for these kinds of applications. Studies that evaluated dental software items that were easily available at the time of publication. The occlusal surfaces of the teeth were used to extract features for the tooth model, which was then automatically deformed and adjusted to produce a virtual design or reconstruction of the area and provide the output in all studies developing AI models. The boundaries were segmented for CAD

modeling. Furthermore, the restoration was accurately modeled and duplicated in every article that was included, bearing a strong anatomical similarity to the original tooth [22, 23, 26].

However, all of the studies used a juvenile dentition to develop their tooth models, and very few considered the antagonist and the sites of contact with neighboring teeth throughout the automatization process. Positive advancements have shown how different prosthodontic features may be built using AI models in CAD modeling. To give a credible reconstructed dental repair for a range of clinical settings, more developments are needed to develop a system that can distinguish different tooth geometries, including worn or old dentition or occlusion types [24, 25, 27, 28]. The research investigated the degree of occlusal morphological similarity between hand-crafted restorations made by dental laboratory personnel and chairside restorations milled using an AI model linked to dental CAD software [26-29].

For a prosthetic reconstruction to be effective, it requires a thorough treatment plan, sufficient backward planning, and neat, practical implementation, including dental laboratory operations. Prosthetic artificial intelligence has the potential to identify premolars and molars with periodontal defects with 90% and 95% accuracy, respectively [30, 31]. However, because of the visual field of periapical radiographs and the redundancy of the imaging features, this technique is unable to distinguish between early lesions or provide a definitive diagnosis of periodontal disease.

AI use in prosthetic dentistry has created a plethora of novel opportunities, such as programmed denture tooth positioning, autonomous framework designs for removable dental prostheses, and the ability to create occlusal morphology in crown contemplation of opposing teeth, even in cases of wear or fracture. In the end, AI is a teaching tool that guides graduate students, postgraduate students, and first-year students alike. Less experienced undergraduate students may also progress in their professions thanks to AI [31-35].

AI has several benefits and may be used in a range of treatment techniques. Convolutional neural networks (CNNs) based on AI were used in research by Lee J *et al.* [23] to classify implants using periapical and panoramic radiography. The results of the research show that the AI-CNN system performs almost as well as humans in classifying implant operations. Potential error-causing variables include poor cementation, occlusion, incorrect placement, and interproximal repair. An AI model was proposed by Lerner *et al.* [36] to lower the possibility of these errors. To develop an AI framework that will categorize dental arches and utilize CNN to assist with denture fabrication, Takahashi *et al.* [30] carried out a detailed examination. Computer-based autonomous learning approaches categorized the training dataset. AI-

enhanced reality improved enjoyment and reduced anxiety in patients. AI will become better at making appointments, providing music and entertainment that patients want, and even helping them relax [30, 37-40].

Conclusion

AI is used more often in prosthodontics and is improving the rehabilitation of individuals needing prosthodontic treatment. Removable, fixed, maxillofacial, and implant prosthodontics all benefit from AI. Using AI improves the functionality and acceptability of prosthodontic therapy, and the likelihood of human mistakes is decreased. Additionally, it was discovered that prosthodontic implant applications gain the most from AI. Researchers have also been discovered to employ AI to develop dentistry and general health solutions.

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