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Original Article

Artificial Intelligence in Prosthodontics: Transforming Diagnosis and Treatment Planning

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ABSTRACT

The field of prosthodontics, which is a combination of art and science, is devoted to the complete treatment of patients with dental disorders caused by inadequate or missing teeth, as well as concerns affecting the oral and maxillofacial tissues. Its primary goals include diagnosis, planning, rehabilitation, and preserving patients' functional, pleasant, and healthy oral conditions. Replacing the prosthesis is the main treatment strategy for this problem. Prosthodontics is mainly concerned with the design and construction of fixed and removable dental prostheses, as well as implant surgery, maxillofacial prostheses, and the improvement of finishing margins next to the tooth to maximize the fit and extension of the prosthesis. It is also utilized to identify the ideal shade of the tooth for cosmetic reasons and to maintain the maxillomandibular relationship. The purpose of the present study is to investigate the role of artificial intelligence (AI) in prosthodontics to evaluate its effectiveness and success. The use of AI in prosthodontics is growing, which is improving the rehabilitation of patients requiring prosthodontic treatment. In the domains of implant, maxillofacial, fixed, and removable prosthodontics, AI has noteworthy benefits. In addition to reducing the likelihood of human mistakes, the use of AI improves the effectiveness and acceptability of prosthodontic treatment. In addition, it has been shown that the field of prosthodontic implant applications benefits the most from AI. AI is also being used by researchers to create dentistry and general healthcare solutions.

Keywords: Artificial intelligence, Prosthodontics, Digital dentistry, Systematic review

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Introduction

The application of artificial intelligence (AI) in dentistry is still in its early phases, as it is in other fields. There are four primary fields in which AI is employed in dentistry. These categories consist of diagnosis, decision-making, therapy planning, and

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treatment forecasting of results. The main application of AI in dentistry that has received substantial attention is in the realm of diagnostics. Integrating AI into dental practice offers the potential to reduce dentists' workload by improving diagnostic reliability and precision. On the one hand, it has been observed that dentists are increasingly embracing computer technology to inform their decision-making procedures [1, 2].

However, there is an increasing tendency in dental computer systems toward more intelligence, preciseness, and dependability. Currently, research on AI is being conducted in several dental specialties. Metrics including accuracy, sensitivity, specificity, F1 score, and AUC area are essential for assessing the model's performance. The distribution of data throughout the training, test, and validation sets must also be taken into account. Finally, the study plan needs to be well thought out. It is still difficult to compare memory efficiency across several published dental AI studies using the receiver operating characteristic (ROC) curve. As previously said, most of the publications simply addressed a portion of the subject. The MICLAIM checklist was created to attain similar degrees of usefulness and openness in the use of AI in the medical industry.

The purpose of the present study is to investigate the role of AI in prosthodontics to evaluate its effectiveness and success.

The role of AI in prosthodontics

Examining, analyzing, strategically intervening, and maintaining patients' oral and maxillofacial structures is the focus of prosthodontics, a branch of dentistry that includes both art and science. It focuses on treating conditions that result from the lack or insufficiency of teeth and related tissues. Replacing the prosthesis is the main therapeutic strategy for this problem [3]. The administration and creation of both permanent and removable dental prostheses are the main areas of concentration for prosthodontics. 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 uses machine-learning algorithms to mimic human cognition and behavior. This model is based on a statistical analysis of historical data and was trained to utilize data collected in the past. The exponential expansion of digital data makes it possible to teach AI systems to provide conclusions that are more and more accurate. Utilizing artificial intelligence-based technology for automated diagnostics, predictive evaluations, and classification or diagnostic tools witnessed significant shifts. Prosthodontics uses every aspect of modern dental technology. An intraoral scanner was used to take digital impressions in place of the more traditional methods. Intraoral scanners are reliable enough to be utilized frequently while creating a short-span FPD or simply one crown. Nonetheless, advancements in the scanning sector made it possible to use it for complete denture production and maxillofacial intraoral scans [5-7].

Following an intraoral scan in the realm of fixed prosthodontics, the AI system was able to accurately detect margins. Both fixed and removable dental prostheses are made using “computer-aided design/computer-aided manufacturing,” or CAD/CAM. Utilizing information gathered from several natural crowns, this technology can produce the best crown designs for a variety of situations.

To help patients achieve the visually beautiful lips they have long desired, digital technology has been increasingly prevalent in the field of dentistry in recent years. The foundation of every therapeutic procedure that alters a patient's smile is the digital depiction of their anatomical makeup. 3D face tracking and affordable virtual 3D data hybrids, like intraoral scans, face scans, and fragmented cone beam computed tomography (CBCT), are among the technologies in this area. Early smile designs were created utilizing straightforward sheet drawings that were taken from patients' two-dimensional printed photos [8, 9].

The use of AI in the field of implant prosthodontics

Both the patient and the doctor must follow the highest prosthetic standards in the field of prosthodontics. A substantial investment of time and resources is needed to produce a flawless product, yet in certain cases, more improvements are needed. Time and resources can be saved by customizing medical equipment to a patient's preferences through the integration of a design and manufacturing unit within a computer system. A thorough knowledge of dental anatomy is frequently taken into consideration when assessing aesthetics. A conventional structure was used in contrast to this. Combining intraoral scanning methods with cone beam computed tomography (CBCT) is the best strategy for dental implant treatment. The possibility to combine these two fields and create cutting-edge prosthetic solutions for the future is presented by the application

of AI in implant dentistry. The primary focus areas in prosthodontics include the treatment of temporary and removable dental prostheses, the creation of precise margins around the teeth to improve the prosthesis's alignment and durability, implant surgery, maxillofacial prosthesis fabrication, the preservation of ideal maxillo-mandibular relationships, and tooth color selection to improve aesthetic appeal [10].

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

In the field of prosthodontics, patients and medical professionals have similar expectations about the quality of the prostheses that are provided. Several people must be involved and a significant amount of resources must be allocated to get the best results. Individualized medical prostheses may be developed and manufactured through the use of computers' built-in design and manufacturing capabilities. There are several ways to do this, including design, milling, and printing. The ability of AI to assess and understand prostheses in the database is greatly aided by the availability of new prosthetic examples that are often uploaded online. Data on dental anatomy was analyzed to evaluate aesthetic factors [11].

The field of maxillofacial prosthesis and its relationship to AI is the subject of interest.

Convolutional neural networks (CNNs), which share structural similarities with real neurons, are employed in artificial intelligence. The artificial ocular prosthesis, developed in the United States, has been successfully utilized by a group of twelve individuals with vision impairment. AI-powered solutions offer the potential to improve visual capabilities without requiring surgical intervention. Dental practitioners may utilize AI and specialized design tools to build visually beautiful prostheses for their patients. This method takes into account anthropological calculations, face dimensions, ethnic concerns, and the desires given by the particular patient. Anyone may use smart reading glasses, regardless of whether they are blind or visually handicapped. This particular piece of equipment is a cutting-edge voice-activated device that can be attached to a variety of eyeglasses. The main goal of this technology is to help and support those who are blind or visually impaired. Text from many sources, including books and smartphone displays, as well as other surfaces, may be quickly scanned and interpreted by the gadget. Its total efficiency is further increased by its demonstration of face recognition and differentiation. Moreover, it enables its users to lead autonomous lives [12].

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

AI development must give human safety a priority to respect the ethical requirements of computer systems. AI has a lot of promise to improve healthcare outcomes when used in clinical settings. This development does, however, also raise important ethical issues that require attention. The wider use of AI is now supported by several well-known IT organizations. Several ethical and risk assessment issues must be carefully considered and assessed before the realization of this idea. To successfully apply AI in the healthcare industry, four basic ethical issues must be addressed: algorithmic fairness and bias reduction, data protection, informed consent for data usage, safety, and transparency. AI usage could make it more difficult for us to hold people accountable for any harm they do. Although not yet known, the possible effects of machines on our ability to assign blame and take responsibility for our actions are substantial. AI in healthcare must follow ethical guidelines to safeguard patients and successfully traverse a changing and frequently disruptive healthcare environment [13].

The prospects

Verification of the generalizability and dependability of the offered AI models is still crucial, requiring the usage of sufficient external data either from recently recruited patients or obtained from other dental facilities. Improving AI models to the point where they can identify early problems that are invisible to the unaided human eye is one of the long-term objectives of the field of AI research in dentistry. The use of AI-enabled algorithms is required due to the utilization of CAD/CAM technology and the increasing need for improved accuracy in prosthodontic implant operations. All phases of AI development, including pre and post-modeling, may have explainability assessed [14].

Materials and Methods

Using the databases PubMed, Medline, and ScienceDirect, a comprehensive evaluation of the literature from 2015-2023 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.

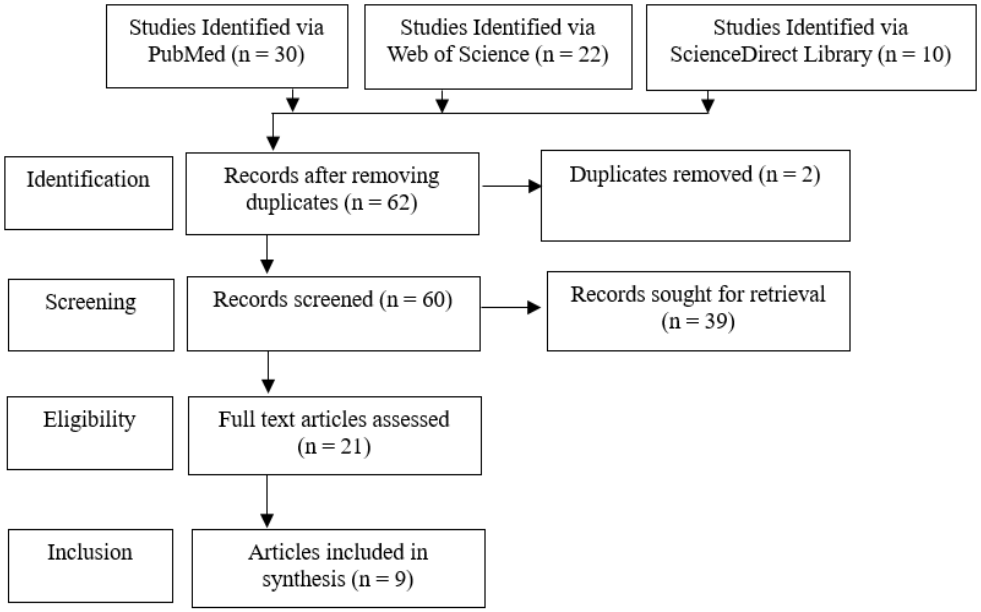


Figure 1. PRISMA flow diagram

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

Reference	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 *et al*. [13]	+	+	+	+	-	+	+
Pareek *et al*. [14]	+	-	+	+	+	+	+
Sikri *et al*. [15]	+	+	+	+	+	+	+
Singi *et al*. [16]	+	+	-	+	+	+	+
Shree *et al*. [17]	+	-	+	+	+	+	+
Shajahan *et al*. [18]	+	+	+	+	+	+	-
Alshadidi *et al*. [19]	+	+	+	+	+	+	-
Moshree *et al*. [20]	+	+	-	+	+	+	+
Singi *et al*. [16]	+	+	+	+	+	+	+

Results and Discussion

The use of AI 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 AI in prosthodontic applications. The primary objective of this systematic study was to assess the effectiveness of AI models in the field of prosthodontics. The approach used in this study was the examination and categorization of a total of 36 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 AI model demonstrated a mean accuracy ranging from 90.6-97.4% in autonomously marking the margin line. Two studies were conducted to develop AI 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 AI model capable of predicting facial expressions.

Pareek *et al*. [14] conducted a comprehensive analysis to examine the prominent disruptive technology of the current period, namely AI. 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*. [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 AI 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*. [16] 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*. [17] 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 AI 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*. [18], their study has shown that AI 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*. [19] investigated the potential use of AI 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*. [20] 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*. [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 *et al*. [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 removable partial dentures - Forecasting changes in facial features in detachable prosthesis	- Better shade matching than conventional selection - Feasibility of automated restoration design - Accurate margin line marking - Improved manufacturing casting - Predictive capability for facial changes - Development of clinical decision support systems	Limited study sample size
Pareek *et al*. [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 *et al*. [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 *et al*. [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 *et al*. [17]	Review AI applications in prosthodontics	- CAD-CAM dentures - Smile designing software - Tooth arrangement for complete dentures -	Positive results for AI applications in the dental field	Mentioned the availability of insufficient and

		Facial deformation prediction - Tooth preparation for crown placement - Implant type recognition - Implant success prediction - Robot for drilling implant site - Mac RPD design		inaccurate details as a disadvantage
Shajahan *et al*. [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 *et al*. [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 *et al*. [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 *et al*. [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 investigation of AI applications in prosthodontics proved AI's predictive power and identified potential for use in automated diagnosis. Because digital technology has advanced rapidly in the last two to three years, the scope of this inquiry has been limited to the last four years. Rather than providing a complete review of AI in dentistry, the purpose of this rigorous study was to show prosthetic AI applications. The results showed that implants, CAD/CAM systems, and studies of orofacial anatomy were among the prosthodontic uses of AI. There were only 24 relevant papers that discussed the application of AI in prosthodontics. Despite its long-standing focus on dynamic caries detection, the field of AIdental image analysis diagnosis has lately broadened its scope to include additional areas of interest, demonstrating the application of AI technology in prosthodontics [21–24]. As a broad and intricate area of dentistry, prosthodontics may benefit from routine AI technology applications.

Eleven studies that evaluated the viability of employing AI models to automate dental restorations to speed up CAD design procedures and reduce manufacturing times were taken into consideration. Reconstructing or estimating the anatomy of dental surfaces, especially the occlusal surface, and precisely reproducing the original geometry are common issues because of the requirement for partial input data from the photographs, including onlay or inlay preparations [25]. Providing a dental restorative design that can be developed employing additive or subtractive approaches is the aim of the AI program. The study examined AI models for CAD modeling or dental restorative design. Two primary areas may be distinguished: research and algorithm development for these types of applications. Research that assessed dental software products that were readily accessible at the time of release. In all research that developed AI models, the tooth model was created by extracting characteristics from the occlusal surfaces of the teeth. The model was then automatically deformed and altered to create a virtual design or reconstruction of the region. For CAD modeling, the borders were divided. Additionally, each piece contained an exact model and replication of the restoration, which bore a significant anatomical resemblance to the original tooth [22, 23, 26].

The opponent and the locations of contact with nearby teeth all over the automatization process were not taken into account in several of the research studies, which all developed their tooth models using a juvenile dentition. Advances have demonstrated that AI models in CAD modeling may be used to build various prosthodontic characteristics. To provide a reliable dental restoration for various clinical contexts, more advancements are required to create a system that can differentiate between various tooth geometries, such as worn or aged dentition or kinds of occlusion [24, 25, 27, 28]. The study examined the level of occlusal morphological resemblance between chairside restorations milled using an AI model connected to dental CAD software and dental laboratory staff's handcrafted restorations [26–29].

For a prosthetic reconstruction to be successful, it needs a comprehensive treatment plan, enough backward planning, and clean, practical execution,

such as dental laboratory procedures. A 90% and 95% precision rate, respectively, in identifying premolars and molars with periodontal abnormalities may be achieved using prosthetic AI [30, 31]. However, due to the periapical radiographs' viewing field and the overlap of the imaging findings, this method cannot differentiate between early lesions or offer a conclusive diagnosis of periodontal disease.

Programmable denture tooth positioning, autonomous framework designs for removable dental prostheses, and the capacity to generate occlusal morphology in crown contemplation of opposing teeth, even in cases of wear or fracture, are just a few of the innovative opportunities brought about by AI's application in prosthetic dentistry. AI is ultimately a teaching tool that helps first-year students, postgraduate students, and graduate students equally. AI may help less seasoned undergraduates advance in their careers as well [31–35].

With its many advantages, AI may be applied to a variety of therapeutic approaches. Research by Lee and Jeong [23] employed periapical and panoramic radiography to categorize implants using convolutional neural networks (CNNs) based on artificial intelligence. The research findings indicate that when it comes to identifying implant procedures, the AI-CNN system performs almost as well as humans. Interproximal repair, improper placement, occlusion, and inadequate cementation are all potential causes of errors. To lessen the likelihood of these mistakes, Lerner *et al*. [36] suggested an AI model. To help with denture production, Takahashi *et al*. [30] conducted a thorough analysis to create an AI framework that will classify dental arches and use CNN. The training dataset was classified using computer-based autonomous learning techniques. AI-enhanced reality made patients happier and less anxious. AI will advance in scheduling appointments, offering patients the music and entertainment they choose, and even assisting with relaxation [30, 37–40].

Conclusion

The application of AI in prosthodontics is increasing, and it is helping those who require prosthodontic therapy recover more quickly. AI helps prosthodontics, including implant, maxillofacial, fixed, and removable prosthodontics. AI increases prosthodontic therapy's acceptance and functionality while lowering the possibility of human error. Furthermore, it was shown that the applications of AI that benefit the most from it are prosthodontic implants. Additionally, researchers are using AI to provide dental and general health solutions.

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Ethics Statement: None

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