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Workflow Intelligence: An Examination of AI-Powered Prosthodontic Diagnostics and Design A Review of literatures

Abstract
With a focus on digital workflows, diagnostic assistance, and computer-aided design and manufacturing procedures, this narrative review examines current uses of artificial intelligence (AI) in prosthodontics. Relevant peer-reviewed research on clinically usable AI-driven techniques in fixed and removable prosthodontics that has been published recently was found in large scientific databases. An analysis of multiple peer-reviewed publications revealed that AI plays a significant role in the interpretation in prosthodontics (e.g., impressions, implant placement, and 3D designing) to support diagnosis and treatment planning. Clinically speaking, the evidence currently available supports the use of AI mainly as a decision-support tool in digital prosthodontic workflows, especially in margin detection and prosthetic design. However, routine clinical adoption of AI is still constrained by inadequate validation and practical applicability. Clinically speaking, the evidence currently available supports the use of AI mainly as a decision-support tool in digital prosthodontic workflows, particularly in margin detection and prosthetic design. However, routine clinical implementation of AI is still inhibited by inadequate validation and practical applicability.

Aim of the Study
The aim of this study is to systematically evaluate the assimilation of AI technologies in modern dentistry, quantifying their sway on diagnostic accuracy, treatment planning workflows, and
clinic operational efficiency.

Introduction
Artificial intelligence (AI) is a contemporary technology that aims to mimic human intelligence and behavior through computer algorithms. It signifies a type of data-centric mathematical model. This model is developed using historical data, which enhances its predictive abilities. The quantity of digital data is unremittingly increasing today, aiding in the training of AI models to produce more defined outcomes. An AI model operates similarly to the human neural network. Additionally, this model is universally known as an Artificial Neural Network (ANN) [(1)].
In digital dentistry, AI is becoming more and more significant. In order to provide diagnostic and therapeutic recommendations for specific patients, AI-based algorithms are analyzing health data, research findings, and treatment approaches. In order to provide diagnostic and therapeutic recommendations for unambiguous patients, AI-based algorithms can evaluate health data, research findings, and treatment approaches [(2)]. The foundation of AI processing algorithms is made up of data and datasets. Large data gives machines a encouraging learning input, allowing for improved decision results [(3)]. Large volumes of data are handled by dental care facilities, increasing the application and significance of AI in dentistry. Diagnosis, decision-making, treatment planning, and therapy predictability are all aided by it.
The most notable application of AI in dentistry is the accurate and

exact diagnosis of dental issues [4, 5]. Machine learning and deep algorithms have been extensively used in dental imaging and surface-based data sets due to their ability to model complex non-linear patterns. In the field of diagnostic dentistry, AI system have been assessed for tasks such as automated detection of dental caries, evaluation bone loss, identification of periapical pathologies and detection of anatomical landmarks in both two- and three-dimensional dental images [6]. Multiple studies have reported that these AI systems attain diagnostic accuracy similar to that of trained professionals, especially in errands involving the interpretation of radiographic image [7]. These results indicated that integrating AI into clinical practices could improve diagnostic consistency and decrease variability in interpretation among dissimilar observers [6-9]. Alongside diagnosing, AI is also used in planning treatments and helping restore missing teeth with dental prosthetics [10]. In implant dentistry, AI is used for placing implants, checking for risks from nearby body structures, and optimization of digitally guided surgical planning [11]. In prosthodontics, AI has been looked into for making fixed crowns denture design, checking how the teeth fit together and the edges of the denture, and predicting how well the restoration will work using computer-aided design and manufacturing systems. These variations show a slow move towards using automation in prosthodontic procedures to make the process more efficient and reproducibility [12-13]. In dentistry, augmented reality (AR) technology is being used to deliver virtual information in addition to real-world information. It helps with orthognathic surgery and dental implant placement in oral and maxillofacial surgery. Additionally, it aids patients see how they will look following treatment in orthodontics, endodontics, and restorative dentistry. Additionally, augmented reality can be utilized in associated with other tools to improve practice and education, allowing faster and more accurate personalized diagnosis, and facilitate patient discussions about dental treatment planning alternatives [14]. The kind of AI that can be applied to prosthodontics is reactive machines. They can be used to automate some procedures, including the creation of dental prostheses, and are made to react to particular inputs. In addition to planning and carrying out prosthodontic procedures, reactive devices can be used to identify and diagnose oral conditions such periodontal disease and caries. Prostheses and other dental appliances can be made using 3D models of teeth and jaws using reactive machines [15].

Deep learning models (DL), neural networks (NN), and machine learning (ML) techniques are likewise employed by AI systems to support clinical decision-making that previously depended on human expertise [16,17].

The development of implantology has made it possible to overcome a number of fixed and detachable prosthesis constraints. Because implant prostheses are more stable and aesthetically pleasing, their acceptance has grown in recent years. Using traditional CAD-CAM systems during the cementation of implant prostheses in the mouth might lead to a number of issues. Numerous factors, including positioning errors, cementation faults, and occlusal or interproximal correction with an abutment, can result in errors. An AI model was presented by Henriette Lerner et al. to reduce these inaccuracies [18].

AI in Dental Diagnosis

AI in dental diagnostics has revolutionized the speed and precision of identifying different dental problems, surpassing conventional diagnostic techniques. Dental imaging data, such as radiographs, CT scans, bitewings and intraoral photos, can now be analyzed and interpreted much more accurately and with higher inter-observer concordance than any dental clinician thanks to modern approaches to the development of AI algorithms based on ML and, in particular DL demonstrated. In the past, radiography and inspection were used to diagnose caries; however, these AI systems outperform the traditional techniques in identifying early-stage lesions [19]. One area that proved the worth of the AI system is assessing dental caries or tooth decay. Caries diagnosis in the past has been done by examination and radiography; however, these AI systems perform better than the conventional methods in diagnosing early-stage lesions [20] (Figure 1).

AI-based treatment planning

AI has greatly changed treatment planning in a number of dental disciplines, improving dental operations' accuracy, personalization, and efficiency. The most common application of AI in treatment planning is in orthodontics, particularly in the development of aligners. AI can create a customized treatment plan that works with clear aligners using a 3D scan of the patient's mouth. The time it takes to align teeth and complete orthodontic treatments can be improved by using such algorithms to more accurately forecast the directions of tooth movement. Patients receive the best orthodontic treatments and are demonstrated to be more satisfied with the therapy as a result of such precise targeting [21].

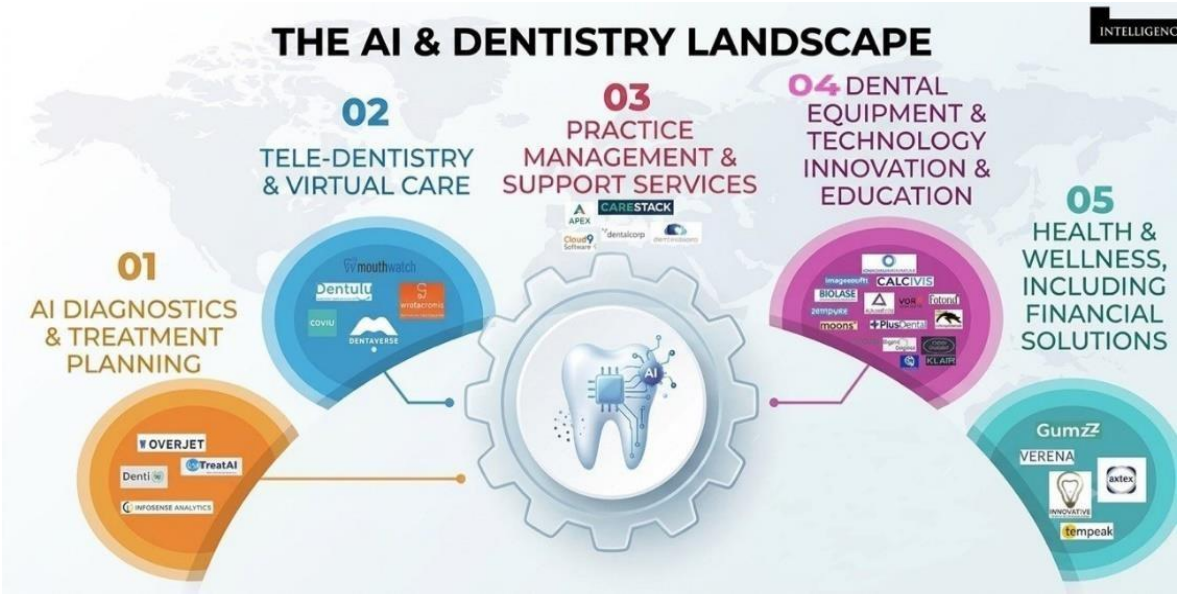

Fig 1: The AI and dentistry landscape by Nissinof (2023)

AI controls the CAD and CAM technologies used in prosthetics design and production.

By using this technology, CAD/CAM systems are able to create dental prosthetics, like crowns, bridges, inlays, onlays and fixed and removable dentures that are customized for each patient's distinct oral architecture. By evaluating large amounts of data, digitally taking scans and imprints, and completing the prosthetic restoration fit, AI improves both functionality, and attractiveness. In comparison to traditional methods, advances in CAD/CAM technology combined with AI processing have compacted human factor intervention, decisions, and time restrictions, resulting in a stronger positive influence on prosthodontic treatment delivery [22]. It is clear how hard prosthetic restorative procedures are, and AI discovered the best way to prepare edentulous places on jaw ridges [13]. advances in CAD/CAM technology combined with AI processing have reduced human factor intervention, decisions, and time restrictions, resulting in a stronger positive influence on prosthodontics treatment delivery [22] (Figure 2).

Virtual patients can be used to replicate patient-related problems and increase the precision of diagnosis and treatment planning. They can serve as a valuable source for research and be utilized to generate digital case scenarios for training. Additionally, a digital representation of the patient can be made using 3D representations of the head, particularly the orofacial area. This can be used to mimic patient-related problems and increase the precision of diagnosis and treatment planning (23).

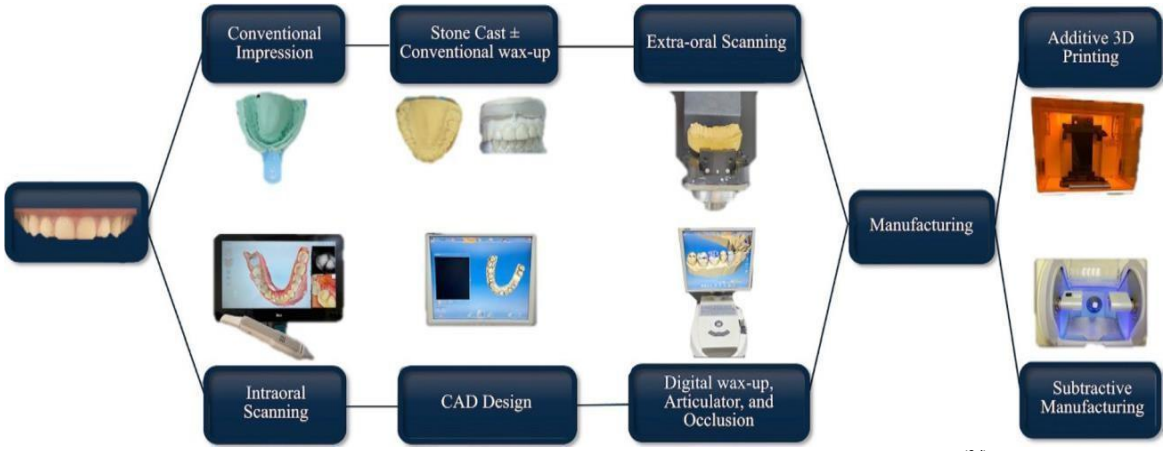

Fig 2: Revolutionizing CAD/CAM-based restorative dental processes [24]

AI and Tooth supported (fixed) and Removable Prosthesis

In order to provide prosthetic rehabilitation for lost teeth and related structures without further loss of the remaining teeth, removable partial dentures (RPD) are less invasive and more affordable [25,26]. The most crucial elements in the creation of RPD are the customization of dentures based on the patient's needs and their design. AI can be used to create a variety of RPD designs and parts. It can independently recommend various framework designs that are most appropriate for the patient [27]. Recently, AI models and convolutional neural networks (CNN) have been used to classify dental arches and assist in the fabrication of RPDs. It

can identify completely edentulous arches, arches with posterior tooth loss or free end jaws, bounded edentulous spaces, and intact arches. High diagnostic accuracy of 99.5% and 97.5% was observed for maxilla and mandible, respectively [28]. AI can be used in conjunction with numerical and experimental models to assess the stress on nearby teeth, implants, or surrounding structures [29].

AI is helpful for a diversity of decision-making patterns, designs, and results in fixed partial dentures (FPDs). AI is helpful in designing the crown's occlusal morphology to match the adjacent and opposing teeth. AI helps define the emerging profile and improve FPD's aesthetics [14].

One of the most important aspects of FPD performance is setting appropriate finish lines and margins. AI is helpful for accurately extracting the margin line. This is especially helpful because it offers comprehensive manual preparations and the likelihood that margins and contours will be over or under extended. Additionally, it helps to keep periodontal tissues and gums healthy. It has been discovered that this AI model has a 97.43% accuracy rate in identifying dental preparation lines [30]. Moreover, AI utilizes its ability to analyze extensive data and offers support in evidence-based dental decision-making [31,32]

AI and Dental Implants

AI's contribution to implant dentistry coincides with the development of intraoral digital scaners, three-dimensional cone beam computed imaging, and fabrication of implant-guided prosthesis [33].

AI uses the data produced by these three-dimensional devices to carefully design and create the implant prosthesis. Peri-apical and panoramic radiographs have been used to create AI models for implant type image recognition [34, 35]. By analyzing osseointegration success, risk factors, and bone anatomy in addition to performing finite element analysis calculations, the prognosis of an implant can be predicted sing AI technology [36]. Implant success can be predicted using a variety of AI methods, including as logistic regression, regression analysis, decision tree learning, and classifier neural networks [37- 39]. AI models can also use implant length, thread length, and thread pitch to determine the stress at the implant-bone interface [40]. Calculating the modulus of elasticity at the implant-bone interface is also helpful [41]. Though, it has been revealed that the success rate of AI in predicting osseointegration or implant success ranges from 62% to 80% [42]. AI can also help with the maxilla-mandibular jaw connection, tooth selection, color selection, defining margins, implant surgery, guided implant prosthesis production, and alignment of the implant and prosthesis [43]. AI is supportive for precisely fabricating and arranging surgical guides for implant placements when combined with digital workflow. AI models can help minimize occlusal, interproximal, and cementation errors [44]. AI-powered implants can be used to create next-generation implant prostheses in a completely modern way. However, some research has found that before AI models are suggested for use in clinical settings, their efficacy and dependability should be assessed [33, 42].

Dental Impressions and AI

Intraoral scanners, and digital cast scanners are patterns of digital technology used to take dental impressions. Because digital impressions are accurate and convenient, they are becoming more and more common in the dental field. Because they are less time and material consuming than traditional impressions and also more economical [45].

Most important welfares of digital impressions are cost-effectiveness, ease, and accuracy. Because digital impressions bid a high-resolution picture of the prepared tooth, they are more accurate than traditional impressions. They are also more economical because they take less time and materials. Additionally, because digital impressions do not require traditional impression materials, they are more pleasant for patients [46]. For fixed restorations such crowns, inlays, onlays, veneers, and fixed partial dentures, digital imprints are most frequently utilized. Additionally, they can be used to design and mill restorations that can be transmitted online to a dental laboratory, as well as to create and mill temporary restorations in a single session. Additionally, using the data from digital impressions, 3D printed or milled casts can be produced [47].

The iTero scanner is an open platform system that offers the ability to connect to a certified design software and chairside milling machine as shown in (Figure1.2). It can be used to fabricate crowns, bridges, inlays and onlays, and veneers in one appointment. Additionally, it can be used to send digital impressions via the internet to a dental laboratory for design and fabrication of physical casts and/or prostheses [47] (Figure 4).

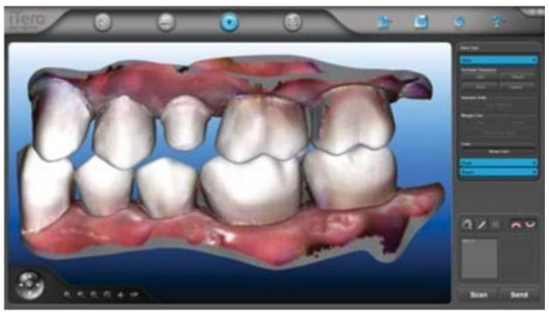

Figure4: Captured screenshots of a partial arch digital impression done with the iTero [48].

AI and Digital Smile Design (DSD)

Since DSD allows physicians to envision and simulate treatment results prior to clinical intervention, it has completely changed the design and execution of aesthetic dental operations [49, 50]. Through digital tools such as 3D facial scans and intraoral photography,

DSD creates precise and patient-centered treatment plans. AI further enriches this process by enabling the automatic identification of facial landmarks, lip contours, and smile lines. AI-based systems can suggest optimized smile designs based on facial harmony and previously analyzed data [51, 52].

Additionally, ML models are being created to forecast long-term aesthetic results and patient satisfaction, which is a big step toward effective and customized smile rehabilitation [53].

The use of AI in DSD is not without restrictions, despite the developments. For example, the VisagiSMile concept, which aims to link personality traits with face features, is still a subjective and mainly unproven method that necessitates critical distance in scientific debate. A significant obstacle is the possibility of dataset bias, wherein AI models trained on small or ethnocentric datasets might not provide designs that are both aesthetically pleasing and culturally appropriate for a variety of patient populations. Additionally, strong clinical validation studies that focus on patient-reported results and the long-term viability of AI-generated designs are lacking in the present literature. In order to overcome these constraints, future studies must include a variety of international datasets and develop unvarying metrics for assessing the subjective and cultural heterogeneity of aesthetics. This transferal will help ensure that AI-assisted DSD evolves into a truly personalized and universally applicable clinical tool (54 55).

Limitation of AI

AI workflow in prosthodontics is disadvantaged by a number of multifarious issues, from methodological flaws to technical limits. The "black box" aspect of DL models, where the decision-making process is opaque, is a major technological issue that makes it challenging for physicians to confirm the reasoning behind a particular diagnosis or design.

AI efficacy is also highly dependent on the quality and filtering of the data; systems trained on biased or non-standardized datasets might not be able to take into account of the wide variations in patient anatomy, cultural aesthetic preferences, and various scanning methods [56].

Methodology

This research utilized a literature review methodology informed by sources [57, 58]. Relevant
materials were located through organized database searches that applied specific inclusion and exclusion criteria. The chosen literature underwent critical analysis to examine the applications of AI, as well as its advantages, challenges, and potential future developments in the field of dentistry.

The including criteria for this narrative review studies must have been published from 2000 onwards and be presented in English. Regarding their relevance, they should concentrate on the use of AI in dentistry, including diagnostics or treatment planning and prosthodontics specifically focusing on AI's impact on clinical decision-making or patient care. Acceptable types of studies comprise peer-reviewed articles and systematic reviews, all of which must be accessible in full-text format either online or through academic databases. Furthermore, the articles must also discuss ethical considerations or data privacy issues related to AI.

Conversely, studies will be excluded if they were published before 2020 or written in languages other than English. Publications are also excluded if they are unrelated to AI or its use in dentistry, or if they only mention AI without providing detailed analyses of its role in the field. Non-peer-reviewed publications, opinion pieces,
and editorials are omitted, along with abstract-only or otherwise inaccessible full-text articles. Finally, any studies that do not discuss the ethical or legal aspects of AI in dentistry are excluded from consideration.

Ethical and Legal Considerations

The rise of AI in dentistry brings significant ethical and legal considerations, particularly regarding data privacy, security, and accountability. AI systems currently depend on large patient health-related data, such as dental records, medical histories, imaging data, and many others, to enhance algorithm learning and pre¬cision.30 Such dependence creates new risks for the protection of patients' data from access, violations, and unauthorized use. There and then,

keeping to data protection laws like the GDPR common in European countries is a paramount factor toward ensuring patients trust their physicians, henceforth embracing ethical practice [59] there are legal implications because patients will sometimes suffer from misdiagnosis or receive a wrong treatment due to the clinical decision support (CDS) (Figure 4).

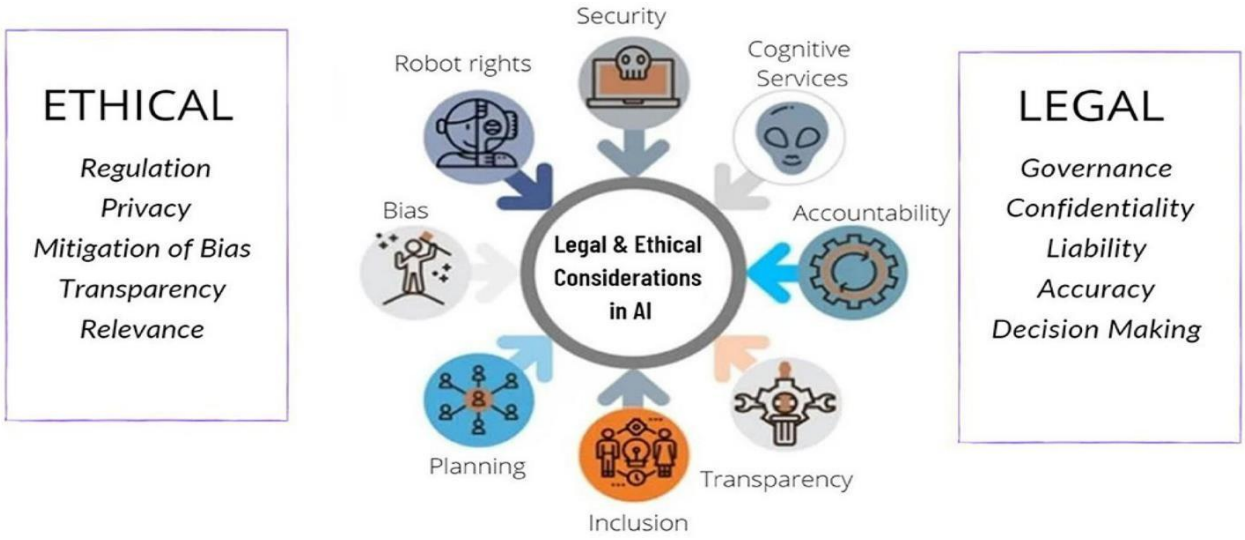

Fig 4: Ethical and legal considerations of AI in healthcare by Naik et al [60].

Purpose of the Study

The purpose of this study is to consider the revolutionary potential of artificial intelligence in dental healthcare by analyzing its function in operational efficacy, treatment planning, and
diagnostics. The quality of clinical decisions is enriched by AI apps that use ML and NN, which also optimize time-scheduled operations and direct enhancements in patient care [61, 62].

The purpose of this study is to govern how AI technologies sustenance patient-centered care,
treatment procedures, and early diagnosis. Additionally, it highlights the deficiencies of the AI incorporation, such as data privacy complications, ethical problems, and execution challenges; nonetheless, ways to overcome these constraints in order to get the best out of the use of AI in the present dentistry practice are also discussed. In summary, the goal of this academic effort is to provide a thorough understanding of how AI could improve dentistry and spur innovation to craft new dental practices.

Objectives of the Study

This paper reviews the use of AI in dental diagnosis and treatment planning, assesses its advantages and disadvantages, and debates ethical issues. Future developments that could
improve the provision of dental care are also highlighted in the study. Main objectives of this narrative review are

- To sightsee the use of AI in dentistry diagnosis and how it affects efficiency and accuracy.
- To examine how AI is used in prosthodontics, and restorative dentistry treatment planning.
- To evaluate the advantages and difficulties of incorporating AI technologies into clinical dentistry.
- To inspect the ethical issues related to the application of AI in dentistry.
- To determine potential AI improvements and future directions that could improve the provision of dental care.

Discussion

A strong contrast in the maturity of AI applications within prosthodontics is revealed by the synthesis of the studied material. AI is excellent at objectively analyzing visual data, such as radiographs and 3D scans, and it provides high accuracy for diagnostic tasks like margin detection and bone volume measurement.

On the other hand, its application in subjective, aesthetic areas such as DSD is still mostly at the exploring stage. This distinction is crucial: AI is now a speculative tool for qualitative tasks (aesthetic and psychological integration) but a high-reliability instrument for measurable tasks (diagnostic and precision fabrication).

The improved accuracy of clinical decision-making is an immediate effect of AI. For example, AI-assisted margin detection improves the marginal fit of restorations by standardizing and automating the formerly laborious and subjective process of identifying the finish line.

This workflow essentially transforms the workflow from a data-gathering process to a decision-evaluation process by shifting the physicians' role from manual data processing to critical examination of AI-generated recommendations. The AI algorithm itself is not the main obstacle to future development; rather, it is the ongoing validation and improvement of the input data to close the gap between technical accuracy and clinical application. Verified datasets is highly valued in recent research. AI systems have the potential to become unparalleled diagnostic tools if they are trained solely on precise and verified clinical data. Additionally, we saw how AI has made its way into the CAD/CAM field, with promising outcomes in prosthesis design. However, in order to realize their full potential, these instruments are still in the developmental stage and require additional time and clinical validation.

Additionally, close cooperation between prosthodontic professionals and AI technologists is crucial. Together, they can develop extremely effective instruments that drastically lessen clinical workload without sacrificing accuracy. Additionally, AI can improve the patient experience by enabling mockups of the final prosthetic outcome prior to the start of treatment. This could allow patients to have a preview of their future smiles and

request modifications, resulting in more individualized care.

Robotics, which is regarded as AI's future in therapeutic settings, offers both tremendous potential and formidable obstacles. Although robotic-assisted dentistry has the potential to completely transform the way that treatments are delivered, its uptake is now constrained by high costs and technical requirements. Even while these technologies might not yet be completely incorporated into standard medical treatment, as advancements continue, their role is anticipated to grow in the near future. The worry that AI would take the place of dentists—a viewpoint that sees AI as a threat rather than a helpful tool—stands evident in a number of research. AI cannot, however, take the role of human intellect, empathy, and clinical judgment. Clinicians must stay up to speed, embrace new technologies, and learn how to use AI tools to their advantage rather than seeing AI as a replacement for clinical experts. Those who do so will find AI to be a powerful assistant rather than a rival.

Conclusion

Prior to prosthetic rehabilitation, AI is employed for periodontal deficient teeth diagnosis, treatment planning, and identification. AI is also helpful for error detection, shade choosing, occlusal morphology, margin detection, tooth preparation, and cosmetic makeover. AI is also helpful for creating digitally implant-guided prostheses and predicting implant success. But AI has drawbacks as well as ethical and legal issues that need to be addressed before it can be used in real-world situations.

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