



# Artificial intelligence in periodontology and implantology—a narrative review

Safiya Fatima Khan<sup>1^</sup>, Abubakar Siddique<sup>2^</sup>, Asim Mustafa Khan<sup>3^</sup>, Bhavya Shetty<sup>4^</sup>, Ibrahim Fazal<sup>5^</sup>

<sup>1</sup>Department of Periodontology, Al Wafa Centre for Dental and Dermatology, Unayzah, Saudi Arabia; <sup>2</sup>Discipline of Clinical Pharmacy, School of Pharmaceutical Sciences, Universiti Sains Malaysia, Penang, Malaysia; <sup>3</sup>Department of Biomedical Science, College of Dentistry, Imam Abdulrahman Bin Faisal University, Dammam, Saudi Arabia; <sup>4</sup>Department of Periodontology, Faculty of Dental Sciences, Ramaiah University of Applied Sciences, Bangalore, India; <sup>5</sup>Department of Periodontology and Implantology, Al Bernie Medical Complex, Al Ahsa, Saudi Arabia

*Contributions:* (I) Conception and design: SF Khan, A Siddique, AM Khan, B Shetty; (II) Administrative support: SF Khan, A Siddique, AM Khan, I Fazal; (III) Provision of study materials or patients: SF Khan, A Siddique, B Shetty, I Fazal; (IV) Collection and assembly of data: SF Khan, AM Khan, B Shetty, I Fazal; (V) Data analysis and interpretation: A Siddique, AM Khan, B Shetty, I Fazal; (VI) Manuscript writing: All authors; (VII) Final approval of manuscript: All authors.

*Correspondence to:* Safiya Fatima Khan, BDS, MDS. Registrar, Department of Periodontology, Al Wafa Centre for Dental and Dermatology, Al Madinah Road, Unayzah 56219, Qassim, Saudi Arabia. Email: safisupernova@gmail.com.

**Background and Objective:** Artificial intelligence (AI) in dentistry is a fast-expanding field that primarily aims to help dentists provide excellent care to patients by streamlining procedures and saving time. AI is revolutionizing dentistry by enabling more precision, reduced errors, and a reduction in staffing needs. This article aims to review the applications of AI across various facets of periodontal diagnosis and treatment planning, along with its advantages and drawbacks.

**Methods:** A comprehensive search was carried out utilizing the databases such as Google Scholar, PubMed, MEDLINE, and Embase, using the keywords “Periodontics AND AI”, “Periodontology AND Artificial Intelligence”, “Periodontology AND neural networks”, and “AI AND periodontal diseases and periodontal therapy”. All the relevant clinical studies, systematic reviews, and meta-analyses were extracted. Only studies published in English were selected. After a detailed review of the abstracts, the most relevant papers related to our topic were included, and any irrelevant articles were excluded.

**Key Content and Findings:** AI has shown positive results in the detection and classification of periodontal disease, periodontal risk assessment (PRA), assessment of bone level, detection of halitosis, treatment planning for dental implants, detection of implant type, optimization of implant designs, prediction of treatment outcomes, and also in the management of a dental practice.

**Conclusions:** AI can improve the effectiveness of periodontists as decision aids and decision-making tools. To gain widespread implementation, AI systems must receive regulatory approval, incorporation with public healthcare systems, standardization for reliable operation, clinical advice and training, and appropriate financing for continuous operation. However, it must be highlighted that there are limitations concerning their practical clinical use which need to be addressed in future studies.

**Keywords:** Artificial intelligence (AI); periodontology; periodontal diseases; periodontal therapy; neural networks

Received: 11 December 2023; Accepted: 07 March 2024; Published online: 25 March 2024.

doi: 10.21037/jmai-23-186

View this article at: <https://dx.doi.org/10.21037/jmai-23-186>

<sup>^</sup> ORCID: Safiya Fatima Khan, 0000-0003-4117-128X; Abubakar Siddique, 0000-0001-5320-1656; Asim Mustafa Khan, 0000-0003-2120-0178; Bhavya Shetty, 0000-0001-8701-3864; Ibrahim Fazal, 0000-0003-1618-883X.

## Introduction

Artificial intelligence (AI) is justifiably one of the most popular buzzwords in technology at present that is revolutionizing all facets of human existence (1). AI is the process of teaching a computer, a computer-controlled robot, or software to think intelligently in the same way that humans do. AI is achieved by examining the characteristics of the human brain and by assessing the cognitive process, leading to the development of intelligent technology (2). AI is defined as “the branch of science and engineering associated with computational knowledge which is commonly referred to as intelligent behavior, as well as the development of systems exhibiting similar behavior”. Artificial intelligent systems are programs that allow computers to function in ways that seem intelligent. Alan Turing [1950], a British mathematician, was one of the pioneers of AI. The term ‘Turing test’, was named after him, which is explained as a computer’s intelligent behavior and its ability to accomplish cognitive tasks on par with humans (3).

The main subdivisions of AI include deep learning (DL), machine learning (ML), robotics, and artificial neural networks (ANNs). AI works in two phases, i.e., a training and a testing phase. The characteristics, associations, and patterns in the data are taught to the AI model in the training phase. Teaching the model to make correct decisions or predictions is the objective of the training phase. The trained AI model makes decisions or predictions for fresh data during the testing phase which were not given during the training phase (4).

AI in dentistry is a fast-expanding field that primarily aims to help dentists provide excellent care to patients by streamlining procedures and saving time (5). AI is revolutionizing dentistry by enabling more precision, reduced errors, and a reduction in staffing needs. It can carry out several tasks in a dental clinic, such as appointment scheduling, and helping with the formulation of a clinical diagnosis and treatment plan (6). AI-based tools aid in enhancing the quality of healthcare at reduced costs for a wider population, and ultimately create the way for personalized, participatory, predictive, and preventive dentistry. Any application of AI in dentistry should show quantifiable benefits, such as improving patient empowerment and support, enhancing accessibility and quality of care, boosting efficiency and safety of services, expanding medical research, or promoting sustainability (7).

In orthodontics, AI has shown good, sensitivity,

specificity, precision, and accuracy in the detection and classification of malocclusion. Neural networks can help in the diagnosis and treatment planning, marking of cephalometric points, evaluating the anatomy, analyzing growth and development, predicting the need for orthodontic extraction, and assessing treatment results (5,6). AI can also assist in orthodontic practice, including clinical documentation, remote care, and practice guidance (8).

ANN has been used to assess the risk of oral cancer (5). An AI-enabled system has been used to assist dentists in differentiating between temporomandibular joint (TMJ) disorders by converting chief complaints and history of TMJ disorders into computer language (5).

AI can detect caries and restorations, and help in choosing a suitable method for caries excavation in the field of restorative dentistry (6). In endodontics, neural networks can be used to identify root fractures and periapical lesions, assess the root canal system and the viability of dental pulp stem cells, measure the working length, and predict the prognosis for retreatment procedures (6). Diagnocat (Diagnocat Ltd., San Francisco, CA, USA), an AI-based tool has been used favorably to diagnose periapical periodontitis on periapical radiographs (9).

AI can aid in the treatment planning of orthognathic surgery and dental implants, identify bone lesions, and predict the possibility of complications after extraction. According to a recent systematic review, AI models have considerable potential for identifying implant types, predicting the success of implant treatment, and optimizing the implant design (10).

Bernauer *et al.* reported that the latest innovations in AI highlight its use in prosthodontics as a tool for diagnosis, identification, classification, and predictive measures (11). AI is also used in pediatric dentistry to assist clinicians in making appropriate diagnoses, clinical decisions, preventive measures, and effective treatment planning (6).

AI is still in its infancy and is not yet fully applied in periodontology. Its advantages in diagnosis and data analysis indicate that there is a lot to gain by using this tool. However, there is insufficient evidence to comprehensively summarize the applications of AI in periodontology. This article aims to review the applications of AI across various facets of periodontal diagnosis and treatment planning, along with its advantages and drawbacks. We present this article in accordance with the Narrative Review reporting checklist (available at <https://jmai.amegroups.com/article/view/10.21037/jmai-23-186/rc>).

**Table 1** The search strategy summary

Items	Specification
Date of search	25 September 2023, 25 November 2023
Databases and other sources searched	Google Scholar, PubMed, MEDLINE, and Embase
Search terms used	“Periodontics AND AI”, “Periodontology AND Artificial Intelligence”, “Periodontology AND neural networks”, and “AI AND periodontal diseases and periodontal therapy”
Timeframe	2003–2023
Inclusion and exclusion criteria	Inclusion criteria: original articles, clinical trials, and systematic reviews utilizing AI for periodontal diagnosis and treatment, and study designs in which AI was used as the independent variable  Exclusion criteria: studies that were not published in English language, studies which used other software rather than AI-based tools, and studies which used AI for purposes other than periodontology and implantology
Selection process	Conducted independently by first author, consensus was obtained after reviewing the full texts

AI, artificial intelligence.

## Methods

A comprehensive search was carried out utilizing the databases such as Google Scholar, PubMed, MEDLINE, and Embase, using the keywords “Periodontics AND AI”, “Periodontology AND Artificial Intelligence”, “Periodontology AND neural networks”, and “AI AND periodontal diseases and periodontal therapy” (*Table 1*). The publication period was set to 20 years. Original articles, clinical trials, and systematic reviews utilizing AI for periodontal diagnosis and treatment, and study designs in which AI was used as the independent variable were included in this review. Studies that were not published in English language, studies which used other software rather than AI-based tools, and studies which used AI for purposes other than periodontology and implantology were excluded.

A single reviewer screened titles and abstracts. After a detailed review of the abstracts, the most relevant papers related to our topic were included, and any irrelevant articles were excluded. Full texts were reviewed by all the authors to determine their eligibility for studies which met the inclusion criteria, or where there was uncertainty to obtain consensus. Data was extracted from the studies and recorded in a tabulated form. The standardized data collation included the author names, year of publication, and the applications of AI.

The study selection process is outlined in *Figure 1*. A total of 410 articles were identified for screening. In total, 295 texts were excluded after screening for factors not meeting inclusion criteria. Full-text review identified 56

studies for inclusion in the review.

## AI in periodontology

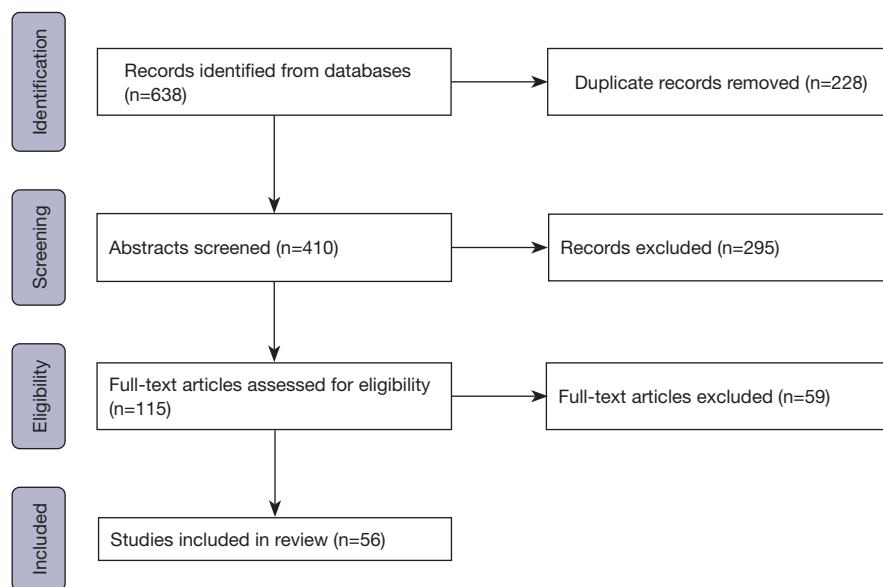
The amount of research on the use of AI models in periodontics has been growing exponentially, which has shown that in the future years, AI will transform periodontology with its various techniques and applications (12). AI can assist in the timely diagnosis of periodontitis by evaluating radiographs and detecting changes in the periodontium, which permits quick intervention and improved treatment results.

### *Detection of periodontal disease*

Intraoral photos and microscopic images of dental plaque have been analyzed by AI-based systems for the detection of periodontal disease (*Table 2*). Good reliability and accuracy have been reported with the use of AI models to assess bone loss and diagnose periodontal disease.

### *Classification of periodontal diseases*

AI models have been used to classify periodontal disease, differentiate between chronic and aggressive periodontitis, and distinguish healthy from inflamed gingival (*Table 3*). AI models have been observed to have a potentially effective and significant ability to identify differences, classify, and identify diseases.



**Figure 1** Study selection flowchart.

**Table 2** Use of AI in the detection of periodontal disease

Author, year	Study	Findings
Lee <i>et al.</i> , 2018 (13)	Deep CNN-based computer-assisted detection system in the diagnosis and prediction of PCT	PCT were diagnosed with an accuracy of 76.7% for molars and 81% for premolars. Extraction was predicted with an accuracy of 73.4% for molars and 82.8% for premolars in severely compromised teeth. The diagnosis and prediction of PCT was successfully performed using the deep CNN algorithm
Aberin <i>et al.</i> , 2018 (14)	Differentiation between periodontitis-affected and healthy dental plaque using microscopic images of dental plaque and the AlexNet architectural model based on CNNs	The model showed an accuracy of 75.5% and a mean square error of 0.05348436995
Balaei <i>et al.</i> , 2017 (15)	Detection of periodontitis for people with limited access to dental personnel and facilities in any healthcare setting considering pretreatment intraoral photos as diseased individuals, and the posttreatment photos as healthy individuals	Pre- and post-treatment have been classified as healthy or diseased individuals with an accuracy of 91.6%. The algorithm is useful as a smartphone application for people with limited access to dental clinics to be screened for periodontitis by health professionals in any healthcare setting, and to monitor the progress of periodontal treatment

AI, artificial intelligence; CNN, convolutional neural network; PCT, periodontally compromised teeth.

### Periodontal risk assessment (PRA)

AI algorithms for PRA have been developed and compared with previous PRA models, producing reliable predictions (Table 4). These AI algorithms have been found to be simple yet beneficial tools for making decisions when predicting periodontal disease since they were simple to comprehend and took into account a variety of characteristics related to periodontal disease.

### Assessment of periodontal bone level

Calculation of radiographic bone loss (RBL) can be complicated, time-consuming, and subjective to the examiner. Hence, AI algorithms have been created to automatically identify RBL and the likelihood of tooth loss and periodontal disease (Table 5). Miller *et al.* [2023] reviewed the potential of AI models to detect RBL for the diagnosis of periodontal disease. They observed that

**Table 3** Use of AI in the classification of periodontal disease

Author, year	Study	Findings
Feres <i>et al.</i> , 2018 (16)	Classification of patients into generalized ChP, generalized AgP, and PH by ML using 40 bacterial species	A support vector classifier using a panel of 40 bacterial species was useful to differentiate between PH, ChP, and AgP. The relative bacterial load could distinguish between AgP and ChP
Rana <i>et al.</i> , 2017 (17)	A ML classifier trained with annotations from dentists that gives pixel-wise inflammation segmentations of color-augmented intraoral photos	The classifier differentiates successfully between healthy and inflamed gingiva with precision and recall of 0.347 and 0.621, respectively. The early diagnosis of periodontal diseases given by this classifier using photos acquired by intraoral imaging devices can be advantageous for dentists and patients
Ozden <i>et al.</i> , 2015 (18)	Classification of periodontal diseases using ANNs, SVM, and DT	DT and SVM showed the best accuracy of 98% in the classification of periodontal diseases with a computational time of 19.91 and 7.00 s, respectively. SVM and DT are simple enough to comprehend; they reflect all the factors associated with periodontal status and are useful as a tool for decision-making and prediction of periodontal disease

AI, artificial intelligence; ChP, chronic periodontitis; AgP, aggressive periodontitis; PH, periodontal health; ML, machine learning; ANN, artificial neural network; SVM, support vector machine; DT, decision tree.

**Table 4** Use of AI in PRA

Author, year	Study	Findings
Moosa <i>et al.</i> , 2023 (19)	ML model to study the association between patient demographics, smoking, treatment received, and severity of periodontal disease before and after treatment	The ML model, random forest regressor, showed less potential for prediction of post-treatment severity. However, it can reflect the associations between patient demographics and disease-specific factors in periodontal disease
Patel <i>et al.</i> , 2022 (20)	Comparison of patient's risk factors in five PRA tools (PRA, PreViser, Sonicare, Cigna, and PRSS developed using ML)	The most precise prediction was given by PRSS (70%), followed by Previser (55%), PRA (35%), Phillips (35%), and Cigna (25%)
Yauney <i>et al.</i> , 2019 (21)	Correlation of periodontal disease with systemic health conditions using a combination of ML, clinical examination, and intraoral fluorescent porphyrin biomarker imaging	The results indicate a positive correlation between systemic health conditions and poor periodontal health. The screening analysis method using ML and images can be used for diagnoses and screening of other systemic diseases
Shankarapillai <i>et al.</i> , 2010 (22)	Prediction of periodontal risk using two ANN algorithms namely: Levenberg Marquardt and Scaled Conjugate Gradient algorithms	The Levenberg Marquardt algorithm outperformed the Scaled Conjugate Gradient algorithm with fewer repetitions, faster convergence, and producing the smallest mean square error in both the training and testing phases. Levenberg Marquardt algorithm can effectively be used as a well-trained neural network for the prediction of the risk for periodontitis

AI, artificial intelligence; PRA, periodontal risk assessment; ML, machine learning; PRSS, Periodontal Risk Scoring System; ANN, artificial neural network.

the mean accuracy in the case of panoramic radiographs ranged between 63% and 94%, while periapical radiographs showed a precision of 25% for detecting mild disease and a high accuracy of 99% for staging of RBL. Specificity for periodontal bone loss ranged between 81% and 83% on cone-beam computed tomography (CBCT), while

sensitivity was 45–72% (26). AI systems can be a good starting point for screening radiographs for periodontal disease. AI models created for the detection of RBL and periodontal disease require further refinement to effectively and consistently evaluate RBL and calculate the periodontal disease risk without the need for assessment by a clinician.

**Table 5** Use of AI in the assessment of periodontal bone level

Author, year	Study	Findings
Alotaibi <i>et al.</i> , 2022 (23)	Detection of alveolar bone loss and classification of the severity of bone loss due to periodontal disease in periapical radiographs in the anterior region of the dental arches using a computer-assisted detection system based on a deep CNN algorithm	Alveolar bone loss was detected with an accuracy of 73%, and the accuracy of classification of the level of severity of the bone loss was 59%. Alveolar bone loss was effectively detected in periapical radiographs using the deep CNN algorithm (VGG-16). Also, the severity of bone loss was detected satisfactorily. Periodontal disease can be detected and staged efficiently using a computer-aided CNN algorithm-based detection system
Chang <i>et al.</i> , 2020 (24)	DL hybrid method for the diagnosis of periodontal bone loss and staging of periodontitis on dental panoramic radiographs	Diagnosis and staging of periodontitis were performed with good reliability and excellent accuracy using the combination of DL and the conventional CAD method
Krois <i>et al.</i> , 2019 (25)	Detection of PBL on panoramic radiographs using deep CNNs	The mean accuracy for classification by CNN was 0.81, and that of the dentists was 0.76. There was no statistically significant difference between CNN and the examiners. The CNN showed comparable ability as dentists in the detection of PBL on panoramic radiographs. Technologies based on ML may help reduce the dentist's efforts

AI, artificial intelligence; CNN, convolutional neural network; DL, deep learning; CAD, computer-aided design; PBL, periodontal bone loss; ML, machine learning.

### *Artificial olfaction for detection of halitosis*

An array of non-selective sensors is used to evaluate the total spectrum of exhaled volatile compounds for artificial olfaction. It is also called an electronic nose as it is a combination of mammalian olfaction and AI which identifies specific patterns of smell and is used as a reference for future identification. The programmed sensor array consists of two subsets in which the bottom panel has a higher affinity for volatile sulfur compounds (VSCs), and the top panel has a higher affinity for non-sulfuric volatile organic compounds. On exposure to the sample, the sensors react simultaneously and the responses are processed for pattern recognition. The software compares the patterns obtained from different sensors with the database of patterns previously obtained during the phases of preclinical training. A decision tree-based classifier determines if a subject has oral or extraoral halitosis. It will also classify the volatolomic pattern based on different systemic diseases in the case of extraoral halitosis (27). Nakhleh *et al.* [2017] demonstrated an AI-based sensor array consisting of 20 functionalized nanomaterials-based sensors that could successfully differentiate between 17 systemic diseases by analyzing the exhaled breath with 86% accuracy (28).

### **AI in implantology**

Implant dentistry has undergone a paradigm shift with the use of AI technology. AI algorithms reduce risks, optimize aesthetics, and improve the accuracy of implant placement. AI-based data analysis improves success rates by providing significant insights into treatment plans that are also patient-specific.

#### *Treatment planning*

CBCT scans are the radiographic method of choice for planning dental implant treatments throughout the world. AI can be helpful for clinicians who face difficulties in evaluating CBCT scans for thorough implant planning and recognition of anatomical structures. Three-dimensional (3D) dental implant placement is essential in the current scenario of prosthetically driven implantology. AI assists dental practitioners in the decision-making process and can be an asset to dental implant planning (*Table 6*).

#### *Detection of implant type*

Numerous implant brands are available throughout the world with prosthetic components and different abutments.

**Table 6** Use of AI in dental implant treatment planning

Author, year	Application of AI in implantology	Findings
Moufti <i>et al.</i> , 2023 (29)	Identify and demarcate edentulous alveolar bone on CBCT images before implant placement	ML showed better accuracy in the segmentation of the edentulous alveolar bone on CBCT images as compared to manual segmentation
Fontenele <i>et al.</i> , 2023 (30)	CNN-based tool for automated segmentation of 3D maxillary alveolar bone on CBCT images	The CNN-based tool provided an accurate segmentation of the maxillary alveolar bone and its crestal contour, which was comparable with the manual segmentation. The AI-based segmentation (51.5±10.9 s) was 116 times faster than manual segmentation
Oliveira-Santos <i>et al.</i> , 2023 (31)	Segmentation of mandibular canal using an AI-based tool in the presence of anatomical variation like the anterior loop	Segmentation of the mandibular canal was achieved accurately even in the presence of an anterior loop
Mangano <i>et al.</i> , 2023 (32)	AI and AR for 3D dental implant planning	The new protocol is time-efficient and effective for planning simple static-guided implant treatment cases in partially edentulous patients. The accuracy of implant placement was acceptable. Conventional software may be replaced by AI and AR technologies for 3D implant planning and guided implant surgery
Sakai <i>et al.</i> , 2023 (33)	Determination of a suitable protocol for implant drilling using CBCT images	The drilling protocol was effectively predicted from CBCT images by the AI model. A decision-making support system based on AI can be developed to improve primary stability
Morgan <i>et al.</i> , 2022 (34)	Segmentation of maxillary sinus from CBCT images using an automated CNN-based model	The CNN model allows a precise generation of 3D models for diagnosis and virtual treatment planning by providing a time-efficient, accurate, and reliable segmentation
Kurt Bayrakdar <i>et al.</i> , 2021 (35)	AI system in implant planning using 3D CBCT images	No statistically significant differences in the bone height measurements between AI and manual measurements. There were statistically significant differences between AI and manual measurements in the bone thickness measurements. Also, the detection accuracy was 72.2% for canals, 66.4% for sinuses/fossae, and 95.3% for missing tooth regions
Kwak <i>et al.</i> , 2020 (36)	Identification and segmentation of mandibular canal on CBCT images using DL networks	The deep CNN model was successfully used for the detection of the mandibular canal

AI, artificial intelligence; CBCT, cone-beam computed tomography; ML, machine learning; CNN, convolutional neural network; 3D, three-dimensional; AR, augmented reality; DL, deep learning.

Additional surgical, periodontal, or prosthetic procedures may be necessary if any complications occur with the implants or their components, and more information, including the implant length, diameter, platform, manufacturer and abutment type will be required during such events. If the implant treatment was provided at a different clinic and if the treatment provider cannot be contacted, it can be cumbersome to obtain the information. The use of AI for the detection of the implant brand can be

a solution to this problem (*Table 7*).

Chaurasia *et al.* [2024] reported an accuracy of 70.75% to 98.19% for the identification and classification of different implant systems (DISs) from periapical and panoramic radiographs using DL models amongst nine studies included in their systematic review and meta-analysis (43). A systematic review by Revilla-León *et al.* [2023] found that the AI models created to identify the type of implant using radiographs showed an accuracy of 93.8–98%, and is a more

**Table 7** Use of AI in the detection of implant type

Author, year	Application of AI in implantology	Findings
Park <i>et al.</i> , 2023 (37)	Automated identification and classification of different DISs using DL algorithm	The automated DL demonstrated a reliable accuracy of 88.53% for classification based on 40,209 periapical and 116,756 panoramic radiographs
da Mata Santos <i>et al.</i> , 2021 (38)	AI-based computer-assisted system for the identification of implant brands using periapical radiographs	The CNN is of good clinical significance which identified implant manufacturers precisely with an accuracy of 85.29%
Benakatti <i>et al.</i> , 2021 (39)	Detection of implant systems from panoramic radiographs using ML	Implant systems can be identified proficiently using the tested ML models, i.e., logistic regression, support vector machine, X boost classifiers, and K Nearest neighbor
Takahashi <i>et al.</i> , 2020 (40)	The DL model for the identification of implant systems	DL models can be used to identify implant systems from panoramic radiographs, which can be helpful for clinicians and patients as well. The training of these models can be improved by adding images of more implant systems for their clinical application
Lee <i>et al.</i> , 2020 (41)	Automated classification of DISs using DCNN	The automated DCNN was very efficient in classifying various types of DISs from dental radiographs, and it could outperform most specialists
Sukegawa <i>et al.</i> , 2020 (42)	Classification of different dental implant brands from panoramic radiographs using deep CNNs	11 types of panoramic radiographs were accurately classified by the VGG-19 and VGG-16 CNNs

AI, artificial intelligence; DIS, dental implant system; DL, deep learning; CNN, convolutional neural network; ML, machine learning; DCNN, deep convolutional neural network.

advanced application of AI in implantology (10).

### **Optimization of implant designs**

AI algorithms have been used in tandem with finite element analysis (FEA) to optimize implant designs (*Table 8*). In a systematic review by Revilla-León *et al.* [2023], it was concluded that the AI models can be used to minimize stress at the implant-bone interface by 36.6% when compared to FEA models, optimize the implant design, length, diameter, and porosity, and enhance FEA calculations, or precisely determine the elastic modulus of the implant-bone interface (10).

### **Prediction of treatment outcomes**

Complications of implant treatment continue to rise with dental implants being the most preferred treatment modality for patients as well as clinicians. These complications are responsible for added procedures and greater treatment costs. Accurate prediction of the therapeutic outcome in implant dentistry is necessary and AI is expected to play a significant role in this area. Neural networks have been used in previous

studies to predict the risk of loss of an implant (*Table 9*). The accuracy of AI algorithms ranged from 62.4% to 80.5% in predicting the success of an implant or osseointegration in a systematic review by Revilla-León *et al.* [2023] (10).

### **Chat-generative pre-trained transformer (ChatGPT) in periodontology**

ChatGPT is an AI program that generates responses that resemble those of a human using DL techniques. Its ability to handle a wide range of topics as a dynamic conversational agent makes it valuable for chatbots, customer support, and other applications. ChatGPT has a multitude of applications in dentistry which include providing telemedicine services for dentistry, aiding in the clinical judgments made by the dentist, enhancing the education of dental students, and helping with the composition of patient information, scientific evaluations, and articles (*Table 10*) (51,52).

Periodontists can use ChatGPT as an informative tool, even though it may not provide perfect accuracy and thorough results without professional supervision. Nevertheless, it must be highlighted that errors may occur.



**Table 8** Use of AI in the optimization of implant designs

Author, year	Application of AI in implantology	Findings
Li <i>et al.</i> , 2019 (44)	Reduction of the stress at the implant-bone interface by optimization approach for dental implants	Implant optimization by support vector regression is reliable and efficient and can replace the finite element method
Roy <i>et al.</i> , 2018 (45)	Utilizing ANNs, FEA, genetic algorithms, and desirability functions in conjunction to design the morphology of dental implants to produce the appropriate microstrain	A genetic algorithm can be used successfully to design a dental implant and obtain the appropriate implant stress and microstrain. ANN model is a good method of optimization to convert the findings of FEA, with reduced computational expenses
Zaw <i>et al.</i> , 2009 (46)	Identify Young's elastic modulus of the tissue between a dental implant and bone using the NN and RBM based rapid inverse analysis method	The RBM-NN method was accurate, efficient, and reliable for inverse material characterizations in noninvasive and/or nondestructive evaluations, with significantly lower computational costs

AI, artificial intelligence; ANN, artificial neural network; FEA, finite element analysis; NN, neural network; RBM, reduced-basis method.

**Table 9** Use of AI in the prediction of treatment outcomes

Author, year	Application of AI in implantology	Findings
Zhang <i>et al.</i> , 2023 (47)	Prediction of implant outcome using periapical and panoramic radiographs	Implant failures were predicted with an accuracy of 87% from periapical and panoramic radiographs using the DL model, which can be helpful to begin clinical intervention at early stages
Oh <i>et al.</i> , 2023 (48)	DL-based prediction of osseointegration of dental implants using plain radiography	Prediction of dental implant osseointegration showed an accuracy of approximately 4/5
Lyakhov <i>et al.</i> , 2022 (49)	Prediction of the success of a single implant by analyzing patient statistics using an AI system	The AI system showed 94.48% accuracy in the detection of patient statistics to predict the success of single implants. This system can improve implant survival and minimize complications by highlighting the less significant patient factors that affect the quality of the implant installation
Huang <i>et al.</i> , 2022 (50)	Prediction of the risk of loss of dental implants using DL based on preoperative CBCT	The IM (created by a combination of clinical features with DL) can assist clinicians in evaluating preoperative risks as it successfully predicts the risk of loss of an implant within 5 years

AI, artificial intelligence; DL, deep learning; CBCT, cone-beam computed tomography; IM, integrated model.

## AI in dental practice

Appointment scheduling is one area where AI is revolutionizing dental practice administration. AI models evaluate several variables, including patient preferences, dentist availability, and treatment durations, to automatically plan appointments in a way that maximizes effectiveness and minimizes disputes. This saves clinicians' time and improves patient satisfaction by ensuring seamless appointment experiences and shorter wait times (53).

The ability of AI to track and optimize patient visits

to preemptively schedule incomplete treatment and launch new-patient marketing campaigns based on profit maximization algorithms is another sophisticated feature of appointment scheduling. ML algorithms that can communicate with dental office software enable this kind of optimization (54).

In terms of general inquiries from patients, all the easy questions can be handled easily by AI. DL algorithms allow for the search of patient records to find the most profitable patient therapy. As a result, assistants can respond more quickly in the event of a patient emergency before

**Table 10** Use of ChatGPT in periodontology

Author, year	Application of AI in implantology	Findings
Babayiğit <i>et al.</i> , 2023 (51)	Evaluation of the accuracy and completeness of the answers to the most frequently asked questions on various topics in periodontology by ChatGPT	With regards to accuracy, ChatGPT's answers to the most frequently asked questions by patients in periodontology were "nearly completely correct", and "adequate" with regards to completeness
Alan <i>et al.</i> , 2023 (52)	Evaluation of the quality of information produced by ChatGPT-4 on PD	It can be regarded as being helpful for PD patients looking for information, despite certain limitations in giving comprehensive information on treatment choice, as it consistently provided accurate information in most of the responses

ChatGPT, chat-generative pre-trained transformer; AI, artificial intelligence; PD, periodontal disease.

the scheduled appointment and spend less time managing prescriptions after surgery. Furthermore, AI can assist the dental practitioner concerning the patient's allergies and any pertinent medical history. AI can also be used by patients participating in tobacco or smoking cessation programs, to schedule important reminders (54).

In contrast to the conventional techniques in dental practices, AI software enables us to create a thorough virtual database for every patient that is simultaneously accessible and user-friendly. Any dental intervention gains reliability because the AI software can acquire all required data from the database more quickly and efficiently than a human (e.g., collection of dental records, radiographs, and extraoral photographs, essential for diagnosis). The AI system's exceptional capacity for learning allows it to be "trained" to carry out a wide range of additional tasks. It can be combined, for example, with imaging techniques such as CBCT and magnetic resonance imaging (MRI) to detect minute variations from normalcy that could have not been noticed otherwise. If seen as a complementary tool, AI can aid with a variety of dental procedures or enhance awareness of periodontal diseases, urging patients to seek timely treatment (54).

Urban *et al.* [2023] reviewed the potential effects of AI support on CBCT data processing in dental clinics and its effects on the transformation of the roles of nurses and dental assistants in the future (55). AI can be used in the following ways for the management of CBCT data:

- (I) AI models can be trained to process and analyze CBCT images for any specific dental condition;
- (II) A comprehensive overview of the patient's oral health can be obtained by integrating CBCT data with other patient information, such as electronic dental records and intraoral scans;

- (III) AI tools can aid nurses and dental assistants in communicating the CBCT data clearly to patients, assisting them to better comprehend their oral health and treatment options;
- (IV) AI models can be used to identify distortions or artifacts that can affect the interpretation of images to ensure good quality of CBCT images.

#### *Advantages of AI*

- (I) Gives accurate and updated information;
- (II) Streamlines automated tasks such as scheduling appointments, patient tracking, obtaining clinical data, and treatment guidance for patients;
- (III) Saves time and resources by automating essential procedures, as a result of which clinicians have more time to examine patients and identify diseases;
- (IV) Assists in research by gathering vast amounts of information from several sources (56).

#### *Disadvantages of AI*

- (I) Needs human surveillance as AI operates with logical reasoning and not with empathy;
- (II) May overlook social variables such as economic, social, and historical issues;
- (III) May lead to unemployment and equity concerns could arise from this variable if it causes professionals to lose their jobs after spending money and effort on healthcare education;
- (IV) Inaccuracies are still possible when there is limited data on specific diseases, environmental factors, or demographics;
- (V) Privacy concerns may arise while using AI as several

multinational companies are unrestricted in their ability to gather and utilize data (56).

## Conclusions

AI can improve the effectiveness of periodontists as decision aids and decision-making tools. To gain widespread implementation, AI systems must receive regulatory approval, incorporation with public healthcare systems, standardization for reliable operation, clinical advice and training, and appropriate financing for continuous operation. However, it must be highlighted that AI cannot replace clinicians; instead, they can support periodontists as they provide patient care, with clinicians adopting roles that best utilize special human skills like compassion, motivation, and comprehensive assimilation as part of a holistic patient-centric healthcare system.

## Acknowledgments

*Funding:* None.

## Footnote

*Reporting Checklist:* The authors have completed the Narrative Review reporting checklist. Available at <https://jmai.amegroups.com/article/view/10.21037/jmai-23-186/rc>

*Peer Review File:* Available at <https://jmai.amegroups.com/article/view/10.21037/jmai-23-186/prf>

*Conflicts of Interest:* All authors have completed the ICMJE uniform disclosure form (available at <https://jmai.amegroups.com/article/view/10.21037/jmai-23-186/coif>). The authors have no conflicts of interest to declare.

*Ethical Statement:* The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

*Open Access Statement:* This is an Open Access article distributed in accordance with the Creative Commons Attribution-NonCommercial-NoDerivs 4.0 International License (CC BY-NC-ND 4.0), which permits the non-commercial replication and distribution of the article with the strict proviso that no changes or edits are made and the original work is properly cited (including links to both the

formal publication through the relevant DOI and the license). See: <https://creativecommons.org/licenses/by-nc-nd/4.0/>.

## References

1. Artificial intelligence. 2023. Accessed: December 6, 2023. Available online: <https://www.oecd.org/digital/artificial-intelligence/>
2. Duggal N. What is Artificial Intelligence and Why It Matters in 2024? 2023. Accessed: December 6, 2023. Available online: <https://www.simplilearn.com/tutorials/artificial-intelligence-tutorial/what-is-artificial-intelligence>
3. Ramesh AN, Kambhampati C, Monson JR, et al. Artificial intelligence in medicine. *Ann R Coll Surg Engl* 2004;86:334-8.
4. Altalhi AM, Alharbi FS, Alhodaithy MA, et al. The Impact of Artificial Intelligence on Dental Implantology: A Narrative Review. *Cureus* 2023;15:e47941.
5. Ramani S, Vijayalakshmi R, Mahendra J, et al. Artificial intelligence in periodontics-An overview. *IP Int J Periodontol Implantol* 2023;8:71-8.
6. Alhaidry HM, Fatani B, Alrayes JO, et al. ChatGPT in Dentistry: A Comprehensive Review. *Cureus* 2023;15:e38317.
7. Schwendicke F, Samek W, Krois J. Artificial Intelligence in Dentistry: Chances and Challenges. *J Dent Res* 2020;99:769-74.
8. Liu J, Zhang C, Shan Z. Application of Artificial Intelligence in Orthodontics: Current State and Future Perspectives. *Healthcare (Basel)* 2023.
9. Issa J, Jaber M, Rifai I, et al. Diagnostic Test Accuracy of Artificial Intelligence in Detecting Periapical Periodontitis on Two-Dimensional Radiographs: A Retrospective Study and Literature Review. *Medicina (Kaunas)* 2023;59:768.
10. Revilla-León M, Gómez-Polo M, Vyas S, et al. Artificial intelligence applications in implant dentistry: A systematic review. *J Prosthet Dent* 2023;129:293-300.
11. Bernauer SA, Zitzmann NU, Joda T. The Use and Performance of Artificial Intelligence in Prosthodontics: A Systematic Review. *Sensors (Basel)* 2021;21:6628.
12. Shirmohammadi A, Ghertasi Oskouei S. The growing footprint of artificial intelligence in periodontology & implant dentistry. *J Adv Periodontol Implant Dent* 2023;15:1-2.
13. Lee JH, Kim DH, Jeong SN, et al. Diagnosis and prediction of periodontally compromised teeth using a deep learning-based convolutional neural network algorithm. *J Periodontal Implant Sci* 2018;48:114-23.

14. Aberin STA, de Goma JC. Detecting periodontal disease using convolutional neural networks. 2018 IEEE 10th International Conference on Humanoid, Nanotechnology, Information Technology, Communication and Control, Environment and Management (HNICEM). IEEE; 2018:1-6.
15. Balaei AT, de Chazal P, Eberhard J, et al. Automatic detection of periodontitis using intra-oral images. *Annu Int Conf IEEE Eng Med Biol Soc* 2017;2017:3906-9.
16. Feres M, Louzoun Y, Haber S, et al. Support vector machine-based differentiation between aggressive and chronic periodontitis using microbial profiles. *Int Dent J* 2018;68:39-46.
17. Rana A, Yauney G, Wong LC, et al. Automated segmentation of gingival diseases from oral images. 2017 IEEE Healthcare Innovations and Point of Care Technologies (HI-POCT). IEEE; 2017:144-7.
18. Ozden FO, Özgönenel O, Özden B, et al. Diagnosis of periodontal diseases using different classification algorithms: a preliminary study. *Niger J Clin Pract* 2015;18:416-21.
19. Moosa Y, Bacha SH, Raza SA, et al. Role of Artificial Intelligence in Periodontology. *Pakistan Journal of Medical & Health Sciences* 2023;17:363-8.
20. Patel JS, Patel K, Vo H, et al. Enhancing an AI-Empowered Periodontal CDSS and Comparing with Traditional Perio-risk Assessment Tools. *AMIA Annu Symp Proc* 2022;2022:846-55.
21. Yauney G, Rana A, Wong LC, et al. Automated process incorporating machine learning segmentation and correlation of oral diseases with systemic health. 2019 41st Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC). IEEE; 2019:3387-93.
22. Shankarapillai R, Mathur LK, Nair MA, et al. Periodontitis risk assessment using two artificial neural networks-a pilot study. *Int J Dent Clin* 2010;2:36-40.
23. Alotaibi G, Awawdeh M, Farook FF, et al. Artificial intelligence (AI) diagnostic tools: utilizing a convolutional neural network (CNN) to assess periodontal bone level radiographically-a retrospective study. *BMC Oral Health* 2022;22:399.
24. Chang HJ, Lee SJ, Yong TH, et al. Deep Learning Hybrid Method to Automatically Diagnose Periodontal Bone Loss and Stage Periodontitis. *Sci Rep* 2020;10:7531.
25. Krois J, Ekert T, Meinhold L, et al. Deep Learning for the Radiographic Detection of Periodontal Bone Loss. *Sci Rep* 2019;9:8495.
26. Miller A, Huang C, Brody ER, et al. CE Credit. Artificial Intelligence Applications for the Radiographic Detection of Periodontal Disease: A Scoping Review. *J Calif Dent Assoc* 2023;51:2206301.
27. Nakhleh MK, Quatredeu M, Haick H. Detection of halitosis in breath: Between the past, present, and future. *Oral Dis* 2018;24:685-95.
28. Nakhleh MK, Amal H, Jeries R, et al. Diagnosis and Classification of 17 Diseases from 1404 Subjects via Pattern Analysis of Exhaled Molecules. *ACS Nano* 2017;11:112-25.
29. Moufti MA, Trabulsi N, Ghousheh M, et al. Developing an Artificial Intelligence Solution to Autosegment the Edentulous Mandibular Bone for Implant Planning. *Eur J Dent* 2023;17:1330-7.
30. Fontenele RC, Gerhardt MDN, Picoli FF, et al. Convolutional neural network-based automated maxillary alveolar bone segmentation on cone-beam computed tomography images. *Clin Oral Implants Res* 2023;34:565-74.
31. Oliveira-Santos N, Jacobs R, Picoli FF, et al. Automated segmentation of the mandibular canal and its anterior loop by deep learning. *Sci Rep* 2023;13:10819.
32. Mangano FG, Admakin O, Lerner H, et al. Artificial intelligence and augmented reality for guided implant surgery planning: A proof of concept. *J Dent* 2023;133:104485.
33. Sakai T, Li H, Shimada T, et al. Development of artificial intelligence model for supporting implant drilling protocol decision making. *J Prosthodont Res* 2023;67:360-5.
34. Morgan N, Van Gerven A, Smolders A, et al. Convolutional neural network for automatic maxillary sinus segmentation on cone-beam computed tomographic images. *Sci Rep* 2022;12:7523.
35. Kurt Bayrakdar S, Orhan K, Bayrakdar IS, et al. A deep learning approach for dental implant planning in cone-beam computed tomography images. *BMC Med Imaging* 2021;21:86.
36. Kwak GH, Kwak EJ, Song JM, et al. Automatic mandibular canal detection using a deep convolutional neural network. *Sci Rep* 2020;10:5711.
37. Park W, Huh JK, Lee JH. Automated deep learning for classification of dental implant radiographs using a large multi-center dataset. *Sci Rep* 2023;13:4862.
38. da Mata Santos RP, Vieira Oliveira Prado HE, Soares Aranha Neto I, et al. Automated Identification of Dental Implants Using Artificial Intelligence. *Int J Oral Maxillofac Implants* 2021;36:918-23.

39. Benakatti VB, Nayakar RP, Anandhalli M. Machine learning for identification of dental implant systems based on shape - A descriptive study. *J Indian Prosthodont Soc* 2021;21:405-11.
40. Takahashi T, Nozaki K, Gonda T, et al. Identification of dental implants using deep learning-pilot study. *Int J Implant Dent* 2020;6:53.
41. Lee JH, Kim YT, Lee JB, et al. A Performance Comparison between Automated Deep Learning and Dental Professionals in Classification of Dental Implant Systems from Dental Imaging: A Multi-Center Study. *Diagnostics (Basel)* 2020;10:910.
42. Sukegawa S, Yoshii K, Hara T, et al. Deep Neural Networks for Dental Implant System Classification. *Biomolecules* 2020;10:984.
43. Chaurasia A, Namachivayam A, Koca-Ünsal RB, et al. Deep-learning performance in identifying and classifying dental implant systems from dental imaging: a systematic review and meta-analysis. *J Periodontal Implant Sci* 2024;54:3-12.
44. Li H, Shi M, Liu X, et al. Uncertainty optimization of dental implant based on finite element method, global sensitivity analysis and support vector regression. *Proc Inst Mech Eng H* 2019;233:232-43.
45. Roy S, Dey S, Khutia N, et al. Design of patient specific dental implant using FE analysis and computational intelligence techniques. *Appl Soft Comput* 2018;65:272-9.
46. Zaw K, Liu GR, Deng B, et al. Rapid identification of elastic modulus of the interface tissue on dental implants surfaces using reduced-basis method and a neural network. *J Biomech* 2009;42:634-41.
47. Zhang C, Fan L, Zhang S, et al. Deep learning based dental implant failure prediction from periapical and panoramic films. *Quant Imaging Med Surg* 2023;13:935-45.
48. Oh S, Kim YJ, Kim J, et al. Deep learning-based prediction of osseointegration for dental implant using plain radiography. *BMC Oral Health* 2023;23:208.
49. Lyakhov PA, Dolgalev AA, Lyakhova UA, et al. Neural network system for analyzing statistical factors of patients for predicting the survival of dental implants. *Front Neuroinform* 2022;16:1067040.
50. Huang N, Liu P, Yan Y, et al. Predicting the risk of dental implant loss using deep learning. *J Clin Periodontol* 2022;49:872-83.
51. Babayiğit O, Tastan Eroglu Z, Ozkan Sen D, et al. Potential Use of ChatGPT for Patient Information in Periodontology: A Descriptive Pilot Study. *Cureus* 2023;15:e48518.
52. Alan R, Alan BM. Utilizing ChatGPT-4 for Providing Information on Periodontal Disease to Patients: A DISCERN Quality Analysis. *Cureus* 2023;15:e46213.
53. How AI will change running a dental practice. 2023. Accessed: December 7, 2023. Available online: [https://samera.co.uk/learning-center/how-ai-will-change-running-a-dental-practice/#Streamlining\\_appointment\\_scheduling\\_and\\_patient\\_management\\_with\\_AI](https://samera.co.uk/learning-center/how-ai-will-change-running-a-dental-practice/#Streamlining_appointment_scheduling_and_patient_management_with_AI)
54. Surdilovic D, Ille T, D'Souza J. Artificial intelligence and dental practice management. *European Journal of Artificial Intelligence and Machine Learning* 2022;1:11-4.
55. Urban R, Haluzová S, Strunga M, et al. AI-assisted CBCT data management in modern dental practice: benefits, limitations and innovations. *Electronics* 2023;12:1710.
56. Pros & cons of artificial intelligence in medicine. 2021. Accessed: December 7, 2023. Available online: <https://drexel.edu/ci/stories/artificial-intelligence-in-medicine-pros-and-cons/>

doi: 10.21037/jmai-23-186

**Cite this article as:** Khan SF, Siddique A, Khan AM, Shetty B, Fazal I. Artificial intelligence in periodontology and implantology—a narrative review. *J Med Artif Intell* 2024;7:6.