Unveiling the prospects and challenges of artificial intelligence in implant dentistry. A systematic review

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ABSTRACT

Aim This systematic review aims to comprehensively evaluate the impact of AI (artificial intelligence) on implant dentistry through an analysis of studies published within the last decade.
Materials and methods A thorough search was conducted across reputable databases - MEDLINE/PubMed, Web of Science, and Scopus - using keywords like "Artificial intelligence in Dentistry," "Dental Implants," "Prosthodontics," and "Implantology." This strategy ensured the inclusion of studies directly pertinent to AI's role in implant dentistry. Adhering to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines ensured transparency in the review process, a total of 154 articles were screened various databases [MEDLINE/PubMed, Web of Science, Scopus]. A meticulous search yielded 12 eligible studies that encompass applications in implant planning, identification, prognosis, and crown design, maintaining the systematic review's quality benchmarks.
Results The integration of AI's predictive capabilities with patient-specific data offers the promise of improved patient care quality. Among the 12 articles, 7 (58.33%) focus on AI-assisted identification of dental implants using IOPA or panoramic radiographs, 3 (25%) on implant planning, 1 (8.3%) on implant prognosis, and 1 (8.3%) on crown design for dental implants. All the studies showed more than 90% accuracy in identifying dental implant systems using AI.
Conclusion This systematic review underscores AI's substantial potential for revolutionizing implant dentistry. While the advantages are compelling, a balanced approach is crucial to tackle challenges. Addressing concerns related to data quality, clinical validation, ethics, and regulatory frameworks is imperative for the responsible and effective integration of AI in implant dentistry.

INTRODUCTION

Prosthodontics is the diagnosis, planning, rehabilitation, and preservation of the function, comfort, appearance, and health of oral structures in patients with missing or inadequate teeth and oral/maxillofacial tissues. It is regarded as both an art and a science (1,2). Artificial tooth replacements and related constructions are the main means by which this field accomplishes its objectives. Prosthodontics has grown significantly in terms of materials, diagnosis and treatment planning, and prosthesis manufacture thanks to developments in digital dentistry (3). The creation of dental prostheses is influenced by many aspects, particularly when there has been tooth loss. Effective alternatives include removable partial dentures, fixed dental prostheses, and implants (4,5). The rehabilitation strategy is determined by the implant chosen and the condition of the alveolar ridge that still exists, necessitating the employment of a variety of procedures during the restorative procedure (6,7,8).
Artificial intelligence (AI) is now widely used in many facets of daily life and has a wide range of technical applications. AI algorithms are essential for conducting target studies, extracting features from images, and conducting image analysis in the medical field (9,10). Utilizing AI in radiology to improve workflow and lessen radiologists' burden has received more attention in recent years. Dental technology has improved, yet it still lags behind medical technology (11,12,13). Standardized digital techniques used in healthcare and labs, like desktop design and CAD/CAM production, are frequently used in conventional dentistry treatments. Artificial intelligence (AI) applications are beginning to appear in the dental industry as digitiza-

tion advances. It can be difficult for edentulous people who need dentures to satisfy both aesthetic and functional requirements. However, AI-driven machine learning in CAD/CAM software holds promise for realigning teeth to restore inter-maxillary connections and assisting in accurate color matching for visually challenging cases involving single central incisors or many front teeth. The use of AI is also expanding in the field of implant prosthodontics, where intraoral detectors are used to locate implants and transmit real-time data into CAD programs for better dental implant design and production (8,14).
Dental implant varieties have multiplied, topping 2000 variations in 2003, in the field of dentistry. Dental professionals have a hurdle as a result of this wide variability (15,16). In response, periapical and panoramic radiographs have been used to create artificial intelligence (AI) models that show promise in the recognition of implant types (17). Additionally, using dental radiographs for precise evaluations, AI has found use in identifying a number of dental disorders, including periodontal disease and dental caries (18,19,20,21,22). The potential of AI extends beyond diagnostics as it is used to create prediction models for evaluating implant prognosis and osteointegration success. These models combine finite element analysis (FEA) calculations with AI algorithms to optimize dental implant designs while considering patient risk factors and ontology criteria. Despite these developments, there are still few in-depth examinations of how AI develops and how it affects implant dentistry (23).
This systematic review's goal was to evaluate how well artificial intelligence (AI) models performed in the field of implant dentistry, including the classification of implant types using periapical and panoramic radiographs, the development of prediction models for osteointegration and implant success, and the improvement of implant designs.

METHODOLOGY

The systematic review process has been registered under registration number CRD42023457489 at the National Institute of Health and Care Research, International Prospective Register of Systematic Reviews database.
A comprehensive systematic search was carried out across three distinct databases - MEDLINE/PubMed, Web of Science, and Scopus. The inclusion criteria for all studies were limited to those published in English within the last 10 years, with the final search conducted on January 1, 2023.
In order to address various aspects of implant dentistry, such as identifying implant types, predicting implant success using patient factors and ontology criteria, and optimizing implant designs with FEA calculations and AI models, a population or problem, intervention, comparison, and outcome (PICO) question was developed. The study emphasized the use of AI as an intervention. The comparison component was dismissed as unimportant. The main result was how well the AI model recognized different implant kinds, predicted implant success using patient characteristics and ontology criteria, and improved implant design optimization using AI and FEA calculations.
What AI techniques are presently utilized in prosthodontics?
How does AI improve clinical decision-making and outcomes within prosthodontics?
How is AI presently employed in prosthodontics clinically, and how reliable is it in diagnosing the appropriate prosthesis for individual patients?
Specifically, a search was performed to identify articles from PubMed and Scopus-indexed journals published between 2017 and 2023 May, using the phrase 'Artificial intelligence in Dentistry', 'Dental Implants', 'Prosthodontics', and 'Implantology'. To conduct the systematic review, five databases were accessed without any date restriction: MEDLINE/PubMed, Embase, Web of Science, Cochrane, and Scopus using MeSH terms [("dental implants" [MeSH] OR "dental prostheses, implant-supported" [MeSH] or "Dental implant, single tooth" [MeSH] OR "dental implant" OR "dental prostheses implant-supported") AND ("Artificial intelligence" [MeSH] OR "Computational Intelligence" OR "Machine Intelligence" OR "Computer Reasoning" OR "AI-based" OR "Computer Vision Systems" OR "Machine learning" [MeSH] OR "Deep learning" [MeSH] OR "Natural Language Processing" [MeSH] OR "Neural Networks, Computer" [MeSH])]. A manual search was also performed, and the search strategy included articles published up to February 21, 2023. Titles and abstracts of the retrieved articles were assessed to determine if they met the inclusion criteria, which encompassed clinical or in vitro studies assessing the performance of AI models in implant dentistry, specifically related to implant type recognition, osteointegration success prediction, and implant design optimization using FEA calculations and AI models.
A total of 154 papers from 4 databases were screened initially from PUBMED and SCOPUS databases, but only 12 papers were selected for systematic review following PRISMA guidelines [Figure 1]. The outcomes of interest were the AI model's performance in recognizing implant types, predicting implant success based on patient risk factors and ontology criteria, and optimizing implant designs using FEA calculations and AI models. The systematic review adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. The whole texts of those articles that satisfied the requirements for inclusion were scrutinized. Research not directly related to implant dentistry (e.g., radiology, periodontics, endodontics, pediatric dentistry, maxillofacial surgery,

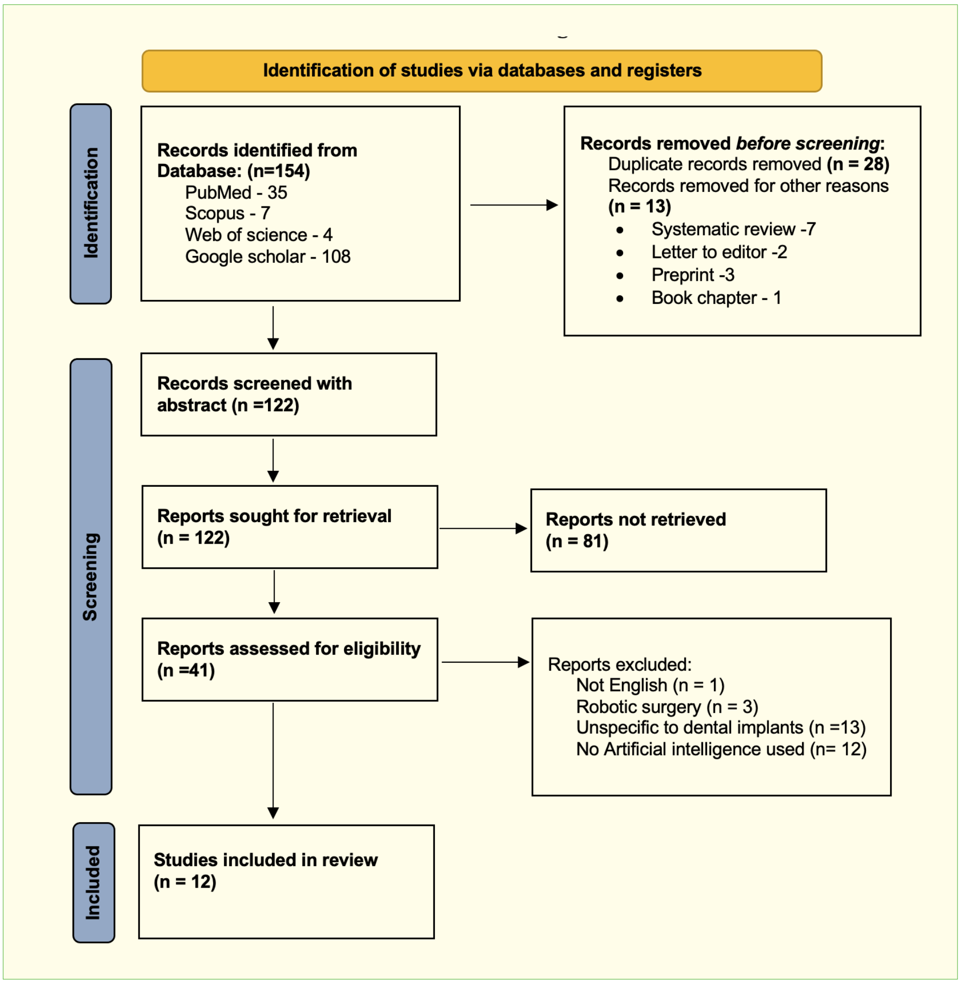

FIG. 1
PRISMA flow chart for selection of articles in the study

and orthodontics), review articles on AI applications, letters to editors, posters, AI models for tooth segmentation, dental robotics, age estimation models, and augmented reality applications) were all deemed ineligible and were excluded from the study. The reviewers compiled data from the included articles into tables.
The study design included English-language publications of both observational research (e.g., case-control and cohort studies) and experimental research (e.g., randomized controlled trials) related to the prosthodontic workflow.

Data Collection

Google Scholar, Scopus, PubMed/MEDLINE, Science Direct, EBSCO host, and Web of Science (MEDLINE, WOS) were searched for scientific studies on AI in prosthodontics. Only prosthodontic papers were extensively collected. The inclusion criteria consisted of English-language articles, evidence-based studies except expert opinions, and content from the previous four years (from 2017-18 to February 2023). Studies excluded were case reports with fewer than ten patients, editorials, reviews without access to or full text of the document, and research articles on animal models.

Data Extraction

Four prosthodontist reviewers (TB, PP, AD & SB) independently reviewed and chose literature on AI in prosthetic dentistry. Following a preliminary matching of titles/abstracts based on inclusion criteria, four reviewers (TB, PP, AD, and SB) independently evaluated and finalized articles through two stages: full-text analysis of chosen papers. Reviewers (TB, PP, AD, and SB) first carried out separate data extraction before comparing and revising their results. The four reviewers independently extracted data using information from several sources, including information about the author(s), publication year, country, study aims, patient records, use of AI, test datasets, and results.

RESULTS

A total of 154 papers from all the databases were screened initially, but only 12 papers [including papers on implant planning (4), implant identification (6), implant prognosis (1), and implant crown design (1)], were selected for systematic review following PRISMA guidelines. The summary of the data derived from the selected papers is given in Table 1. A total of 12 articles were included in this review. 7 (58.33%) of

S.No	Authors	Implication	Origin Country and year	AI type/Aim of AI	Result
1	Bayrakdar SK et al. (24)	Implant planning	Turkey 2023	CBCT assessment/ Diagnocat AI system	For canals, the proportion of right detection was 72.2%; for sinuses/fossae, it was 66.4%. 484 tooth areas (95.3%) were accurately identified. In the premolar and molar regions of the mandible and maxilla, there were no statistically significant differences between the AI and manual measures of bone height ($p > 0.05$).
2	Michelinakis G et al.(17)	Implant identification	USA 2006	Implant recognition system	87 implant producers were found over a 10-month period.
3	Saïd et al.(25)	Implant identification	France 2020	Using a radiograph, a sophisticated CNN could determine the make and model of a dental implant.	In this model, the NPV was 91.5%, the sensitivity was 93.5%, the specificity was 94.2%, and the diagnostic accuracy was 93.8.
4	Lee JH et al.(26)	Implant identification	Korea 2020	to show the effectiveness of deep CNN algorithm in identifying and categorizing DI system	The deep CNN architecture and periodontist got an AUC of 0.956 and 0.891, respectively, using solely panoramic radiography images. Both the periodontist and the deep CNN architecture got an AUC of 0.979 when just using periapical radiography images. CNN's overall AUC was 0.971 compared to periodontists' 0.925.
5	Sukegawa S et al.(27)	Implant identification	Japan 2020	accuracy of deep CNN transfer learning while employing digital photos for DI brand classification and elucidation.	Pretrained weights in the highly calibrated VGG16 model led to the greatest results across all measures, including recall, precision, accuracy, and F-measure.

***Key notes:- AI- Artificial intelligence; CBCT- Cone beam computed tomography; CNN- Convolution neural network; DI- Dental implant; NPV- Negative predictive value; AUC-Area under curve; VGG-Visual geometry group; DL- Deep learning; DSC- dice similarity coefficient; Cad- Computer aided designing*

TABLE 1 Brief result of studies included in the systematic review

the published papers used AI for the identification of different dental implants either in IOPA or Panoramic radiograph, 3 (25%) used AI for implant planning, 1 (8.3%) paper used AI for implant prognosis and other 1 (8.3%) for Crown designing on dental implants. [Figure 2] Most of the studies originated from East Asia, four from South Korea and two from Japan. Other countries from where research papers were included were Germany, France, USA, UAE, Turkey, and Thailand (one each). All the studies showed more than 90% accuracy in identifying dental implant systems using AI. Three studies on implant planning showed promising results but all of them had different methods for assessments. One study of implant prognosis concluded the machine learning methods, the decision tree model and support vector machine, yielded similar results.

DISCUSSION

Using synthetic materials to replace lost teeth and oral/maxillofacial tissues, prosthetic dentistry is essential in restoring oral function, aesthetics, and health. A wave of improvements in information processing, diagnosis, treatment planning, and dental equipment have been brought about by the introduction of digital dentistry (24). For oral rehabilitation to be successful, it is essential to choose the right kind of dental prostheses, such as partial dentures, fixed prostheses, or dental implants (35,36). Dental implants and artificial intelligence (AI) together have the potential to completely transform the healthcare industry. AI has become more popular across a range of industries, and its adoption in dentistry has been notable for its uses in diagnosis, planning dental procedures, and prosthetic reconstruction (11,37). Though artificial in-

6	Lee JH et al.(28)	Implant identification	Korea 2020	to assess the effectiveness of the automated deep CNN for categorizing different kinds of DI systems.	Based on the AUC, Youden index, sensitivity, and specificity for the 2,396 panoramic and periapical radiography pictures, the accuracy of the automated deep CNN was 0.954, respectively.
7	Takahashi T et al.(29)	Implant identification	Japan 2020	an automated system that recognizes DI systems by employing an object detection technique based on deep learning.	This identification system's mean average precision and mean intersection over union, respectively, were 0.71 and 0.72.
8	Seung-Ryong Ha et al.(30)	Implant Prognosis	Korea 2018	Utilizing machine learning techniques, estimate the prognosis of implants	The mesio-distal position of the implant was found to be the most important element in determining its prognosis, according to the data. The decision tree model and the support vector machine, two machine learning techniques, had similar outcomes.
9	Park W et al.(31)	Implant identification	Korea 2023	Analyze the precision of an automated DL algorithm for recognizing and categorizing different types of DI systems (DIS).	For 116,756 panoramic and 40,209 periapical radiographic pictures, the automated DL's performance metrics for accuracy, precision, recall, and F1 score were 88.53%, 85.70%, 82.30%, and 84.00%, respectively. The DL algorithm achieved 87.89% accuracy, 85.20% precision, 81.10% recall, and 83.10% using only panoramic images.
10	RoongruangsilP et al.(32)	Implant planning	Thailand 2021	the investigation of the built AI's learning curve for designing dental implants in the posterior maxilla	Detection was enhanced by 12.50% using the blurred augmented model, but accuracy was 18.34% worse. The cross-sectional picture and panoramic image of the colored augmented model both exhibit the best improvements, at 40% and 18.59%, respectively.
11	Moufti MA et al.(33)	Implant planning	UAE 2023	to create an artificial intelligence (AI) system to recognize and outline edentulous alveolar bone on CBCT prior to implant insertion.	The majority of the sample's teeth were lower molars and premolars. For training and testing, DSC produced average values of 0.89 and 0.78, respectively. 75% of the sample's unilaterally edentulous regions had a better DSC (0.91) than bilateral cases (0.73).
12	Lerner H et al.(34)	Implant crown designing	Germany 2020	CAD of final crown including margin using AI	The monolithic zirconia crowns' three-year cumulative success and survival rates were 99.0% and 91.3%, respectively.

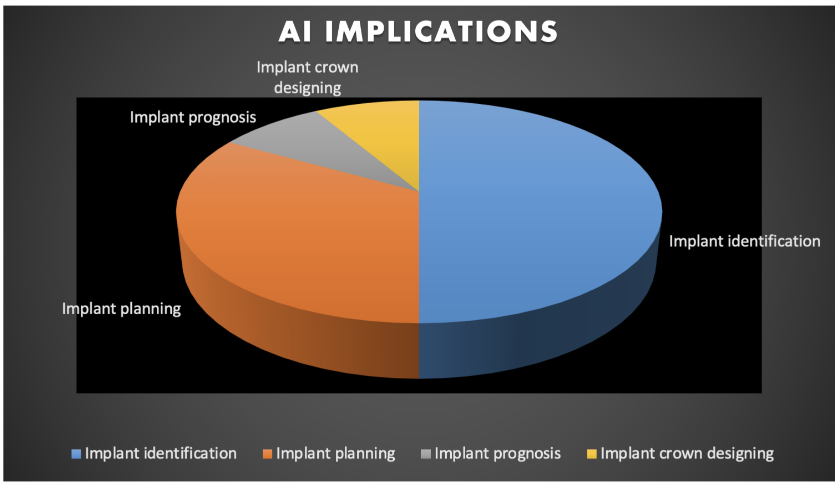

FIG. 2
Simplified pie graph showing proportionality of AI application in different aspect of dental implant

telligence (AI) has already shown useful in the medical field in areas like image analysis and research (38), its integration into dentistry, particularly in the area of dental implants, has been a gradual process (39,40). Digital techniques have long been the backbone of traditional dentistry procedures, but AI-driven innovations are starting to change the game (41).

The ability of AI to help in the identification of diverse dental implant types—a task made difficult by the development of more than 2000 implant varieties as of 2003—represents a noteworthy advancement in this integration (17,25). AI models that use radiographs for implant-type classification have evolved to handle this complexity and display outstanding diagnosis accuracy. Convolutional neural networks (CNNs), a type of deep learning model, have been crucial in attaining accurate implant brand and model identification, sometimes outperforming human expert performance (26,27). Additionally, the scope of AI's power goes beyond diagnosis to include prediction. The success of implants can be predicted using AI-driven prediction models that take both patient-specific and ontological factors into account. To determine dental implant prognosis, machine learning approaches like decision tree models and support vector machines have been used. To give information on implant success rates, these models take into consideration elements like mesiodistal implant placement and other clinical aspects. This ability to forecast outcomes gives clinicians important information they can use to make wise choices and possibly enhance patient outcomes (30,31).

Another important use is the combination of artificial intelligence and implant design. To optimize implant designs, researchers have investigated mixing AI algorithms and finite element analysis (FEA) calculations. This method uses patient-specific data and biomechanical considerations to provide implant designs that put usefulness and longevity first. Incorporating AI into the design process may allow for the customization of implants to meet the demands of specific patients, improving the effectiveness of treatment (29).

There are many benefits of incorporating AI into implant dentistry. More accurate treatment planning may result from improved diagnostics made possible by AI-guided identification of implant kinds from radiographic images (27,28). As AI algorithms analyze patient data and suggest the best courses of action based on unique traits, the efficiency of treatment planning may also be increased. The amount of time and resources needed to provide patient care may be decreased as a result of these decision-making processes being streamlined. Additionally, the ability of AI to anticipate implant success and osteointegration outcomes offers clinicians priceless insights (31). This predictive capability fits in perfectly with a personalized patient care strategy, which may boost patient satisfaction and success rates. However, the incorporation of AI into implant dentistry also presents difficulties that call for careful thought. The quantity and quality of data play a key role in determining how accurate an AI model is (26,27). The task of effectively training AI models on large, varied datasets can be challenging when applied to the field of dentistry. To avoid biases and unreliable results, it is crucial that training data cover a wide range of patient demographics and conditions (27,28).

A tailored approach to health care that incorporates this predictive potential may increase patient satisfaction and success rates. Implant dentistry's use of AI, however, also has challenges that require careful consideration. How accurate an AI model is is heavily influenced by the quantity and quality of data (26,27). When used in dentistry, it might be difficult to successfully train AI models on huge, diverse datasets. Training data must include a wide range of patient demographics and conditions to prevent biases and incorrect outcomes (27,28).

Therefore, it can be argued that the application of AI to implant dentistry has a lot of potential. New opportunities for improving diagnostics, treatment planning, and prosthetic design are presented by AI-powered advancements in implant type detection, osteointegration success prediction, and implant design optimization. The potential benefits are significant, notwithstanding issues with data quality, clinical validation, ethical constraints, and standardization. Dental professionals must navigate these difficulties as the sector develops while utilizing AI's ability to deliver precise, customized, and effective patient care.

CONCLUSION

The application of AI technologies to implant dentistry has shown significant promise for personalized prosthesis design, treatment planning, and diagnostics. The capacity of AI to correctly classify implant kinds from radiographic images enables precise diagnosis, expediting treatment planning, and improving decision-making effectiveness. Along with customized implant designs for improved outcomes and higher patient satisfaction, AI's predictive abilities in evaluating implant performance and prognosis help personalized patient care. However, utilizing these opportunities calls for resolving the difficulties. To avoid biases and mistakes, training AI models requires high-quality data, which calls for representative diversity across patient demographics and illnesses. Responsible implementation requires thorough clinical validation as well as ethical considerations regarding data protection and liability.

Its diagnostic and predictive powers are expected to grow as AI technology develops and datasets increase.

Enhancing patient-specific implant designs through integration with technologies like 3D printing could improve treatment outcomes. The promise of AI in telemedicine could also democratize access to top-notch dental treatment. This future, though, depends on coordinated efforts. Dental experts, researchers, and regulatory agencies should develop standardized practices and guidelines to enable easy AI incorporation. Effective adoption into clinical practice will be ensured by rigorous clinical validation studies. Patient trust will increase if data privacy issues are addressed and AI decision-making is transparent. As a result of AI's fusion with prosthetic dentistry and implantology, diagnostics, treatment planning, and prosthetic design are being redefined. While obstacles still exist, efforts made in concert will enable AI to reach its full potential and improve the accuracy, customization, and effectiveness of dental implant procedures. In order to fully take advantage of AI's disruptive potential for the best patient outcomes and oral health, this momentous juncture requires both visionary innovation and shared responsibilities.

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REFERENCES

1. Mahdi SS, Battineni G, Khawaja M, Allana R, Siddiqui MK, Agha D. How does artificial intelligence impact digital healthcare initiatives? A review of AI applications in dental healthcare. Int J Inf Manag Data Insights. 2023;3:100144.
2. Pareek M, Kaushik B. Artificial intelligence in prosthodontics: A scoping review on current applications and future possibilities. Int J Adv Med. 2022;9:367.
3. Cicciù M. Prosthesis: New Technological Opportunities and Innovative Biomedical Devices. Prosthesis. 2019;1(1):1–2.
4. Paschou T, Rapaccini M, Adrodegari F, Saccani N. Digital servitization in manufacturing: A systematic literature review and research agenda. Ind Mark Manag. 2020;89:278–92.
5. Naddeo P, Laino L, La Noce M, Piattelli A, De Rosa A, Iezzi G, Laino G, Paino F, Papaccio G, Tirino V. Surface biocompatibility of differently textured titanium implants with mesenchymal stem cells. Dent Mater. 2015;31(3):235-43.
6. Shah KC, Lum MG. Treatment planning for the single-tooth implant restoration--general considerations and the pretreatment evaluation. J Calif Dent Assoc. 2008;36(11):827-34.
7. Jihed M, Dallel I, Tobji S, ben Amor A. The Impact of Artificial Intelligence on Contemporary Orthodontic Treatment Planning-A Systematic Review and Meta-Analysis. Sch J Dent Sci. 2022;9:70–87.
8. Alshadidi AAF, Alshahrani AA, Aldosari LIN, Chaturvedi S, Saini RS, Hassan SAB, et al. Investigation on the Application of Artificial Intelligence in Prosthodontics. Applied Sciences. 2023;13(8):5004.
9. Saghiri MA, Vakhnovetsky J, Nadershahi N. Scoping review of artificial intelligence and immersive digital tools in dental education. J Dent Educ. 2022;86(6):736-750.
10. Cicciù M, Fiorillo L, D'Amico C, Gambino D, Amantia EM, Laino L, Crimi S, Campagna P, Bianchi A, Herford AS, Cervino G. 3D Digital Impression Systems Compared with Traditional Techniques in Dentistry: A Recent Data Systematic Review. Materials (Basel). 2020;13(8):1982.
11. Agrawal P, Nikhade P. Artificial Intelligence in Dentistry: Past, Present, and Future. Cureus. 2022;14(7):e27405.
12. Abdinian M, Moshkforoush S, Hemati H, Soltani P, Moshkforoushan M, Spagnuolo G. Comparison of Cone Beam Computed Tomography and Digital Radiography in Detecting Separated Endodontic Files and Strip Perforation. Applied Sciences. 2020;10(23):8726.
13. Rengo C, Spagnuolo G, Ametrano G, Juloski J, Rengo S, Ferrari M. Micro-computerized tomographic analysis of premolars restored with oval and circular posts. Clin Oral Investig. 2014;18(2):571-8.
14. Bernauer SA, Zitzmann NU, Joda T. The Use and Performance of Artificial Intelligence in Prosthodontics: A Systematic Review. Sensors (Basel). 2021;21(19):6628.
15. Jokstad A, Braegger U, Brunski JB, Carr AB, Naert I, Wennerberg A. Quality of dental implants. Int Dent J. 2003;53(6 Suppl 2):409-43.
16. Sahiwal IG, Woody RD, Benson BW, Guillen GE. Radiographic identification of nonthreaded endosseous dental implants. J Prosthet Dent. 2002;87(5):552-62.
17. Michelinakis G, Sharrock A, Barclay CW. Identification of dental implants through the use of Implant Recognition Software (IRS). Int Dent J. 2006;56(4):203-8.
18. Hung K, Montalvao C, Tanaka R, Kawai T, Bornstein MM. The use and performance of artificial intelligence applications in dental and maxillofacial radiology: A systematic review. Dentomaxillofac Radiol. 2020;49(1):20190107.
19. Chang HJ, Lee SJ, Yong TH, Shin NY, Jang BG, Kim JE, Huh KH, Lee SS, Heo MS, Choi SC, Kim TI, Yi WJ. Deep Learning Hybrid Method to Automatically Diagnose Periodontal Bone Loss and Stage Periodontitis. Sci Rep. 2020;10(1):7531.
20. Li H, Zhou J, Zhou Y, Chen J, Gao F, Xu Y, et al. Automatic and interpretable model for periodontitis diagnosis in panoramic radiographs Martel AL et al., editors. Medical image computing and computer assisted intervention e MICCAI 2020. MICCAI 2020. Lecture Notes in Computer Science. 12262. Springer; 2020
21. Feres M, Louzoun Y, Haber S, Faveri M, Figueiredo LC, Levin L. Support vector machine-based differentiation between aggressive and chronic periodontitis using microbial profiles. Int Dent J. 2018;68(1):39-46.
22. Devito KL, de Souza Barbosa F, Felippe Filho WN. An artificial multilayer perceptron neural network for diagnosis of proximal dental caries. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2008;106(6):879-84.
23. Revilla-León M, Gómez-Polo M, Vyas S, Barmak BA, Galluci GO, Att W, Krishnamurthy VR. Artificial intelligence applications in implant dentistry: A systematic review. J Prosthet Dent. 2023;129(2):293-300.
24. Kurt Bayrakdar S, Orhan K, Bayrakdar IS, Bilgir E, Ezhov M, Gusarev M, Shumilov E. A deep learning approach for dental implant planning in cone-beam computed tomography images. BMC Med Imaging. 2021;21(1):86.
25. Hadj Saïd M, Le Roux MK, Catherine JH, Lan R. Development of an Artificial Intelligence Model to Identify a Dental Implant from a Radiograph. Int J Oral Maxillofac Implants. 2020;36(6):1077-82.
26. Lee JH, Jeong SN. Efficacy of deep convolutional neural network algorithm for the identification and classification of dental implant systems, using panoramic and periapical radiographs: A pilot study. Medicine (Baltimore). 2020;99(26):e20787.
27. Sukegawa S, Yoshii K, Hara T, Yamashita K, Nakano K, Yamamoto N, Nagatsuka H, Furuki Y. Deep Neural Networks for Dental Implant System Classification. Biomolecules. 2020;10(7):984.

28. Lee JH, Kim YT, Lee JB, Jeong SN. 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(11):910.
29. Takahashi T, Nozaki K, Gonda T, Mameno T, Wada M, Ikebe K. Identification of dental implants using deep learning-pilot study. Int J Implant Dent. 2020;6(1):53.
30. Ha SR, Park HS, Kim EH, Kim HK, Yang JY, Heo J, Yeo IL. A pilot study using machine learning methods about factors influencing prognosis of dental implants. J Adv Prosthodont. 2018;10(6):395-400.
31. 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(1):4862.
32. Roongruangsilp P, Khongkhunthian P. The Learning Curve of Artificial Intelligence for Dental Implant Treatment Planning: A Descriptive Study. Applied Sciences. 2021;11(21):10159.
33. Moufti MA, Trabulsi N, Ghousheh M, Fattal T, Ashira A, Danishvar S. Developing an Artificial Intelligence Solution to Autosegment the Edentulous Mandibular Bone for Implant Planning. Eur J Dent. 2023 May 12.
34. Lerner H, Mouhyi J, Admakin O, Mangano F. Artificial intelligence in fixed implant prosthodontics: a retrospective study of 106 implant-supported monolithic zirconia crowns inserted in the posterior jaws of 90 patients. BMC Oral Health. 2020 ;20(1):80.
35. Kurtz S, Ong K, Lau E, Mowat F, Halpern M. Projections of primary and revision hip and knee arthroplasty in the United States from 2005 to 2030. J Bone Joint Surg Am. 2007;89(4):780-5.
36. Goodacre CJ, Bernal G, Rungcharassaeng K, Kan JY. Clinical complications with implants and implant prostheses. J Prosthet Dent. 2003;90(2):121-32.
37. Carrillo-Perez F, Pecho OE, Morales JC, Paravina RD, Della Bona A, Ghinea R, Pulgar R, Pérez MDM, Herrera LJ. Applications of artificial intelligence in dentistry: A comprehensive review. J Esthet Restor Dent. 2022;34(1):259-80.
38. Gulshan V, Peng L, Coram M, Stumpe MC, Wu D, Narayanaswamy A, Venugopalan S, Widner K, Madams T, Cuadros J, Kim R, Raman R, Nelson PC, Mega JL, Webster DR. Development and Validation of a Deep Learning Algorithm for Detection of Diabetic Retinopathy in Retinal Fundus Photographs. JAMA. 2016;316(22):2402-10.
39. Heo MS, Kim JE, Hwang JJ, Han SS, Kim JS, Yi WJ, Park IW. Artificial intelligence in oral and maxillofacial radiology: what is currently possible? Dentomaxillofac Radiol. 2021;50(3):20200375.
40. Müller H, Michoux N, Bandon D, Geissbuhler A. A review of content-based image retrieval systems in medical applications-clinical benefits and future directions. Int J Med Inform. 2004;73(1):1-23.
41. Ding H, Wu J, Zhao W, Matinlinna JP, Burrow MF and Tsoi JKH (2023) Artificial intelligence in dentistry—A review. Front. Dent. Med. 2023;4:1085251.

Abbreviations

Abbreviation	Definition
AI	Artificial intelligence
CBCT	Cone beam computed tomography
CNN	Convolution neural network
DI	Dental implant
NPV	Negative predictive value
AUC	Area under curve
VGG	Visual geometry group
DL	Deep learning
DSC	Dice similarity coefficient
CAD	Computer aided designing
TB	Tridib Nath Banerjee
PP	Priyanjali Paul
AD	Anasua Debnath
SB	Saurav Banerjee