REVIEW

CYPRUS
JOURNAL OF MEDICAL SCIENCES

DOI: 10.4274/cjms.2025.2024-101
Cyprus J Med Sci 2025;10(4):218-227

The Use of Artificial Intelligence in Different Dental Applications

Selen Erkul[1], Yunus Emre Özden[1], İdil Özden[2], Bengü Doğu Kaya[3], Burcu Bal[1], Zeynep Özkurt Kayahan[1]

[1]Department of Prosthodontics, Yeditepe University Faculty of Dentistry, İstanbul, Türkiye
[2]Department of Endodontics, Marmara University Faculty of Dentistry, İstanbul, Türkiye
[3]Department of Restorative Dentistry, Marmara University Faculty of Dentistry, İstanbul, Türkiye

Abstract

In response to technological breakthroughs, artificial intelligence (AI) applications are being extensively studied and developed in the fields of medicine and dentistry. AI applications significantly contribute to healthcare services and enhance efficiency by reducing the workload of healthcare professionals. The capacity of machines to exhibit human-like thinking and learning will significantly enhance the early detection and prevention of diseases. Although currently regarded as a supplementary component in dental diagnosis and treatment, it is expected that its significance will further advance in the coming years. This study aims to discuss the current use of AI technology in different branches of dentistry.

Keywords: Artificial intelligence, dentistry, deep learning

INTRODUCTION

Artificial intelligence (AI) involves developing systems that simulate human-like thinking processes in computers.[1] Developments in AI first began in 1943 with Allan Turing's question, "Can machines think?", and John McCarthy first used the term "AI" at a conference in 1956.[2] AI is a general term that encompasses the use of machines and technology to assist in performing tasks that are typically done by humans.[3] Machines can create algorithms based on what they learn from data; thus, they can solve problems without human assistance.[2]

To understand AI, it is necessary to first know its subsets such as machine learning (ML), neural networks (NN), and deep learning (DL) (Figure 1). The process of extracting the required data from internet data pools is called ML. ML involves algorithms that identify patterns and predict outcomes directly from existing datasets, operating autonomously without human guidance.[4]

NN are specialized ML algorithms designed to mimic the structure and functioning of the human brain. They consist of interconnected layers of artificial neurons (perceptrons) to replicate human neural processes. These networks enable computers to simulate human cognitive abilities such as learning, reasoning, and problem-solving.[2]

On the other hand, DL, a subset of ML, enables computers to learn how to process data on their own. DL extends the concept of NN by using multiple interconnected layers, forming complex architectures known as Deep NN.[2,5,6] The depth of these networks refers to the numerous algorithmic layers that work together, each contributing incrementally to interpreting data, but lacking significance individually.

Within DL, models such as artificial NN (ANN) and convolutional NN (CNN) play pivotal roles, especially in fields like dentistry. CNNs, particularly proficient in analyzing visual data, are widely utilized in dental research for tasks such as classifying, segmenting, and detecting features

To cite this article: Erkul S, Özden YE, Özden İ, Doğu Kaya B, Bal B, Özkurt Kayahan Z. The use of artificial intelligence in different dental applications. Cyprus J Med Sci. 2025;10(4):218-227

ORCID IDs of the authors: S.E. 0000-0002-0376-9830; Y.E.Ö. 0000-0002-4080-7744; İ.Ö. 0000-0003-0838-4355; B.D.K. 0000-0002-3116-2016; B.B. 0000-0002-1849-7006; Z.Ö.K. 0000-0002-3320-9244.

Corresponding author: Selen Erkul
E-mail: selen.mert@yeditepe.edu.tr
ORCID ID: orcid.org/0000-0002-0376-9830

Received: 25.10.2024
Accepted: 17.04.2025
Publication Date: 15.08.2025

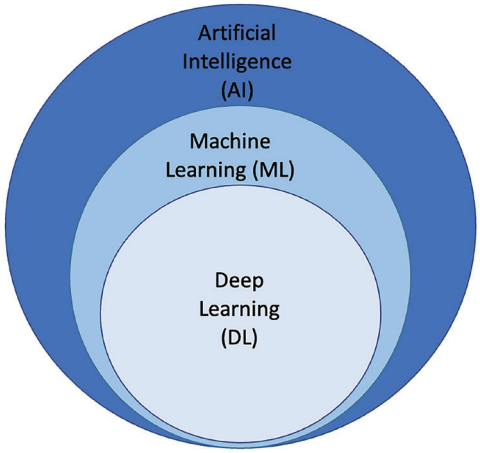

Figure 1. Subsets of artificial intelligence.

in dental radiographs. Conversely, ANNs, which feature multilayered architectures capable of refining and interpreting data progressively, excel at identifying intricate patterns-much like a dentist enhances radiograph images to discern different dental structures clearly.

Overall, the advanced NN structures of DL position it as a more powerful and effective tool for addressing complex problems compared to traditional ML approaches.

With advances in technology, AI has begun to modernize the traditional aspects of dentistry.[7] AI can perform many simple procedures in dental clinics with higher precision, using less personnel, and fewer errors compared to human performance. With the increase in digitalization, AI is used in many areas, from scheduling and coordinating regular appointments to assisting in clinical diagnosis and treatment planning and from designing prostheses to improving education. Integrating AI technology into dentistry reduces human-induced errors and saves time and money.[8] The purpose of this review is to examine the role and usage possibilities of AI as an auxiliary element in different departments of modern dentistry.

Table 1 summarizes the application of AI in different fields of dentistry.

Artificial Intelligence Applications in Oral, Dental and Maxillofacial Radiology

Radiographic evaluations are used for two basic purposes in dentistry. The first of these purposes, "analysis and differentiation of radiological features of normal and pathological formations in tissues", can be performed automatically using AI applications nowadays. The second purpose, "determination of preliminary and differential diagnoses, by evaluating data together with clinical examination findings", cannot yet be fully achieved with AI applications.[9,10] AI applications are most appropriate for identifying a potential abnormality and also assist the clinician in the final decision, but should not be the decision maker.[11] Therefore, AI applications can be used as a supportive tool in the field of oral, dental and maxillofacial radiology.

Putra et al.[12] discovered that the number of AI studies in the radiology field has been consistently increasing each year, with a significant increase beginning in 2020. Two-dimensional radiographs, including periapical, panoramic, and cephalometric radiographs, were the first used in the field of radiological studies.[10] After Flores et al.[13] proposed the AI-supported cone beam computed tomography (CBCT) model to differentiate periapical cysts from granulomas in 2009, 3-dimensional images have become more prevalent in the studies. The DL method was found to be the most frequently used AI technique, accounting for 59% of radiograph analyses, followed by ML, and other computer imaging methods in 26% of cases.[12]

Hung et al.[14] published a review in 2020 that focuses on four primary topics related to the use of AI in the fields of oral, dental, and maxillofacial radiology. These topics are automatic localization of cephalometric landmarks, diagnosis of osteoporosis, classification and segmentation of maxillofacial cysts and tumors, and identification of periodontal and periapical diseases.[14] In addition to these, AI applications are also used in areas such as numbering of teeth, detection of caries, extra roots and supernumerary teeth, evaluation of root morphology and determination of vertical root fractures, diagnosis of osteoporosis, and Sjögren syndrome.[15-18]

Table 1. Application of AI in different fields of dentistry.

Oral, dental and maxillofacial radiology	Automated interpretation of radiographs Segmentation of dental and bone structures Detection of pathological formations Detection and numbering of teeth
Oral, dental and maxillofacial surgery	3D image analysis for surgical planning Integration of robotic surgical systems Prediction of complication risks Diagnosis of cysts and tumors Localization of anatomic landmarks
Periodontology	Early diagnosis of periodontal diseases Detection of bone loss and gingival recession Monitoring treatment progress and prognosis prediction Detection of plaque accumulation
Endodontics	Analysis of root canal morphology in radiographs Assessment of root canal filling quality Detection of apical lesions Measuring working length Predicting treatment success and prognosis
Restorative dentistry	Detection of dental pathologies and treatments in radiographs and photographs Detection of vertical fractures in CBCT Predict prognosis of restorations
Prosthodontics	Digital prosthesis design using CAD/CAM systems Optimization of 3D printing processes Personalized prosthetic planning Assessing tooth color
Pedodontics	Tracking dental development stages in children Caries risk analysis Behavioral analysis for treatment planning
Orthodontics	Automated cephalometric analyses Simulation of tooth movements Individualized treatment planning Detect crowding and malocclusion from photographs

CBCT: Cone beam computed tomography, CAD: Computer-aided design, CAM: Computer-aided manufacturing.

Chen et al.[19] achieved an accuracy value of over 90% in their AI study on periapical radiographs for the detection and numbering of teeth. According to the results of the studies on AI use in detecting periapical pathologies, it has been reported that the accuracy rate of AI applications can aid clinicians in diagnosis.[15,20] In their study, Fukuda et al.[21] found the accuracy of AI in detecting vertical root fractures on panoramic radiographs to be 93%. Kise et al.[22] and Ariji et al.[23] conducted studies on Sjögren syndrome and the detection of lymph node metastases on computed tomography, and reported that AI models had high diagnostic accuracy. According to the study conducted by Lee et al.[24,25] on the diagnosis of osteoporosis using panoramic radiographs, AI applications showed an accuracy rate of 98.5%, a rate compatible with that of maxillofacial radiologists.

Artificial Intelligence Applications in Oral, Dental and Maxillofacial Surgery

In the field of oral, dental, and maxillofacial surgery, AI applications are used to perform several tasks such as radiographic image quality improvement, diagnosis of cysts and tumors, and localization of anatomic landmarks for improved surgical planning, precision, and patient outcomes. With the support of AI software, the aim is to determine enhanced and personalized treatment planning, while surgeons can also benefit from AI's real-time assistance and feedback during intraoperative decision-making, which increases surgical accuracy and decreases complications.[26]

Vinayahalingam et al.[27] evaluated the relationship of the third molar teeth with the inferior alveolar nerve using AI software in their study. They reported that the AI software was successful in preventing possible surgical complications, but the algorithm and accuracy rates should be increased for its use in clinical routine. Zhang et al.[28] in a study evaluating postoperative edema after extraction of mandibular impacted third molars, reported that AI applications showed 98% accuracy. According to the results of this study, AI applications are important in predicting the prognosis of the surgical procedure.[28]

Another area where AI can be used in maxillofacial surgery is implantology. Park et al.[29] scompared in 2023 compared the identification of various implant systems from radiographic images by an AI program and by dentists. They reported that the pre-trained and modified AI program gave statistically-significantly higher rates of correct answers in a shorter time compared to experienced and inexperienced clinicians.[29] Kurt Bayrakdar et al.[30] evaluated the success of the AI software in implant planning using CBCT in their 2021 study. According to the results of the study, the AI software was found to be more successful in determining bone height and width than manual methods. It has been reported that incorporating these systems in implant planning would simplify the work of clinicians. However, further comprehensive research about the evaluation of environmental anatomical structures using AI systems is required.

AI applications can also be used to scan and classify lesions in the oral mucosa and detect suspicious areas. The early diagnosis of malignant tumors in the oral region, especially in areas where health services are limited, with the help of AI-supported software programs is thought to affect morbidity and mortality rates.[31] Studies have reported that AI applications are also promising in the diagnosis of head and neck cancers.[32,33]

Artificial Intelligence Applications in Periodontology

In the field of periodontology, AI is used for various purposes such as detecting plaque accumulation and gingivitis, measuring pocket depth during probing, assessing alveolar bone loss, early identification of periodontitis through radiographic analysis, detecting changes in bone density, and diagnosing peri-implantitis and halitosis.[34-43] AI can also be used to identify individuals at a high risk of developing periodontal diseases. This approach enables the implementation of preventive interventions, which can decrease the severity and frequency of the disease. Several retrospective studies specifically designed for periodontal diseases and based on extensive electronic dental information have been conducted to assess the impact of AI algorithms.[44-46] These studies suggest that the probability of having periodontal disease can be determined by examining demographic factors, general health indicators, behaviors, blood values, medical history, dental hygiene, and periodontal parameters.[47] Shimpi et al.[44] developed a predictive model for periodontal disease using supervised ML techniques. Decision trees and ANNs were more accurate in classifying patients as having low or high risk of periodontitis compared to other models (sensitivity =87.08% and specificity =93.5%). Another retrospective study reported that ANNs performed well in terms of accuracy (90.0% - 98.1%), specificity (89.4% - 97.9%), and sensitivity (91.1% - 98.6%) in classifying patients as having aggressive or chronic periodontitis.[44]

Uzun Saylan et al.[48], in their study evaluated the effectiveness of AI models in identifying alveolar bone loss as present or absent across different regions. They found that regional bone loss detection was more successful than general bone loss detection in panoramic radiographs.[48] Shankarapillai et al.[49] used 230 textual topics for effective periodontitis risk prediction. However, the actual reliability of these innovative prediction methods for periodontitis has not yet been verified.

It should be noted that providing more standardization and methodology development in this area is needed. The decrease in the number of participants due to retrospective analysis and division of patients into subgroups leads to changes in the results of the studies. AI can significantly improve the diagnosis and treatment of periodontal diseases. Evaluating the amount of bone loss alone is not sufficient to determine the severity and extent of periodontal disease. Clinical attachment loss and tooth loss should also be evaluated. Factors such as general health status, number of cigarettes smoked per day, psychological state, and family history, also determine diagnosis and prognosis. Therefore, in future research, it is necessary to use an AI model in which information regarding these parameters is defined and organized to create modern AI applications. After the necessary development, AI can play an important role in the diagnosis of long-term periodontal diseases.

Artificial Intelligence Applications in Endodontics

The use of AI applications in endodontics is increasing in all the stages such as diagnosis, treatment planning, and follow-up.[50] The use of AI applications in many areas such as determining pulpal status[51,52], measuring working length[53,54] , detecting periapical lesions[20,53,55-57], or root fractures[20,58-60], evaluating root anatomy[61-63], evaluating the difficulty of the case[64], and predicting treatment success and prognosis[65-67] has been investigated in studies. In addition, AI programs are applied to explaining the working principles of endodontic devices and are also used in clinical education.[68-70]

Although AI cannot replace clinical examination for the assessment of the pulpal condition, it can be used as a supportive instrument to enhance diagnostic accuracy. Tumbelaka et al.[51] demonstrated the ability of an ANN trained using periapical radiographs to differentiate between healthy pulp, necrotic pulp, and pulpitis. Similarly, Zheng et al.[52] demonstrated that the accuracy of diagnosing deep caries and pulpitis was greatly improved by training CNNs using periapical radiographs combined with clinical parameters. While AI has the potential to identify different pulpal conditions using radiographs, it is essential to acknowledge its limitations. Radiographic assessments should be complemented by clinical examinations and other diagnostic tools, such as pulp and periapical tests, to ensure a thorough and accurate diagnosis in clinical practice.

In root canal treatment, success is mainly related to the correct determination of the working length, since the termination of the instruments within the apical region affects the prognosis of the treatment. Saghiri et al.[53] first introduced the use of AI in determining the working length. In their study, they evaluated the effectiveness of AI and showed that the AI program determined the location of the minor apical constriction with higher accuracy compared to professional endodontists.[54]

One of the applications of AI in endodontics is the radiological diagnosis of apical periodontitis, which is often performed using periapical and panoramic radiographs or CBCT.[56,57] Setzer et al.[56] reported that the rate of detecting periapical lesions correctly from CBCT images with a DL model was 93%. Similarly, Orhan et al.[20] tried to detect periapical lesions in CBCT images using CNN in their study. The results of the study indicated that CNN achieved 92.8% accuracy, and this rate was similar to the results obtained by experienced dentists.[20]

The use of AI systems has also been evaluated in the detection of vertical root fractures, which is a difficult clinical condition to diagnose. The AI systems have been found to provide very high accuracy in the determination of fracture lines.[20,58,59]

It has been stated that AI systems can provide a clear clinical picture of root canal morphology and a 3D modification that can be used as a guide for clinicians in challenging cases.[71] In the studies conducted[61-63], the use of DL models and CNN for the detection and classification of C-shaped canals was evaluated. The results indicate that AI can be a helpful technique in overcoming complex diagnostic difficulties.[61-63]

A new approach developed by Mallishery et al.[64] tested an automated system using AI to assess case difficulty and support referral decisions. The system used the American Association of Endodontists' Endodontic Case Difficulty Assessment Form and 500 clinical cases. The results of the study showed that AI has the potential for automation in assessing the complexity of endodontic cases.[64]

Campo et al.[65] used AI software to assess whether a case required endodontic treatment and stated that the application provided valuable contributions to the treatment decision-making process. Similarly, Herbst et al.[66] evaluated the use of AI techniques to predict endodontic treatment failure and concluded that AI applications can assist clinicians in determining the factors associated with failure. Another study conducted by Hasan et al.[67] in 2023 evaluated root canal filling success using AI system. This study successfully classified filling errors and demonstrated the effectiveness of these algorithms in evaluating endodontic treatment outcomes.[67]

Artificial Intelligence Applications in Restorative Dentistry

In restorative dentistry, clinical examinations and radiographs, are commonly used to diagnose, and plan treatment for patients' teeth and existing restorations. Considering the latest developments in medicine and dentistry focused on automating diagnosis, AI may have a substantial impact on the detection and classification of dental pathologies in the future.[8,72] The use of AI models to diagnose dental caries and vertical fractures, detect tooth margins, and predict restoration failure has increased significantly since 2019.[73] It has been emphasized that AI systems can have an important place in the field of restorative dentistry by improving clinical decision-making diagnosis, treatment planning, and predicting prognosis.[74] A systematic review reported that non-specialist dentists can obtain diagnostic assistance from DL systems.[8]

DL has been shown to detect dental pathologies or treatments on bitewing radiographs[75,76], periapical radiographs[52,77,78], panoramic images[79,80], or infrared light transillumination images.[81] In restorative dentistry, AI models are frequently used on periapical radiographs.[77] It has been shown that AI can be used for caries diagnosis and can detect both enamel and dentin caries (with a sensitivity of 60% for enamel caries and 97% for dentin caries). AI has shown nearly 100% success in detecting caries in cavities up to 0.6 mm deep.[73] A study conducted with bitewing radiographs reported that computer-aided tools for caries detection facilitate the diagnosis and classification of dental caries and help in appropriate treatment planning and monitoring of disease progression. In another study, the defect matching of the AI-aided computer program was found to be 96% on average for "no caries", 21% for score 1 (outer enamel defect), 23% for score 2 (inner enamel defect), 35% for score 3 (outer dentin defect) and 41% for score 4 (inner dentin defect).[82]

In addition, AI is used in the detection of tooth fractures and cracks. It has been reported that when AI models are used together with tomography in fracture detection, they provide more accurate and specific diagnostic results.[20] In a study using intraoral photographs, it was reported that ceramic, metal, amalgam or composite restorations compatible with tooth color in posterior teeth are can be automatically categorized with an accuracy rate of over 90% using DL-based AI. Researchers have shown that such AI-based methods can support dentists in the future.[83] In another study using intraoral photographs of patients with fissure sealants, the AI system categorized the restorations as "sound," "adequate," and "inadequate" with a diagnostic accuracy of approximately 90%.[85]

AI can also be used for treatment planning, and process. For example, it has been reported that AI programs can accurately predict the depth and type of finish line to be used for a specific tooth preparation and has an accuracy of 90.6 to 97.4% in this regard.[73] It is thought that AI programs can analyze images of tooth preparations predict areas of debonding in resin composite restorations comment on the prognosis of composite restorations, and enhance long-term success.[85]

AI applications are also used to compare the accuracy and repeatability of intraoral scanners or computer-aided design/computer-aided manufacturing (CAD/CAM) systems, as well as to articulate models obtained using scanners, both of which are essential components of digital restorative dentistry. It has been shown that AI can eliminate errors that may arise during data transfer.[86] Three-dimensional models of prepared teeth can be created, dental restorations can be designed, and these designed restorations can be milled or printed with CAD/CAM systems. In this context, AI models can be used to automate the design of dental restorations through customized reconstruction.[87]

Artificial Intelligence Applications in Prosthodontics

In prosthetic dentistry, the incorporation of CAD/CAM technologies into the treatment procedures has emerged as a significant advancement, enhancing the efficacy of therapies. Mangano et al.[88], in their study with 25 patients, found that 40 monolithic zirconia crowns, which were designed with the assistance of AI and a fully digital process, had a survival rate of 97.5% and an overall success rate of 92.4%.

In CAD/CAM systems, AI is now being used in the initial stages of work, specifically the impression phase as well as the design phase. AI support is utilized in modern devices to enhance the precision of scanning in impressions captured by intraoral scanners, and to offer users a more convenient scanning experience.[89] These devices improve the clinician's experience and enhance treatment comfort by shortening scanning time and ensuring that any missing parts may be filled with the software. This is achieved by excluding tissues like the cheek and tongue from the image during scanning. Furthermore, AI enables operations like the automatic drawing of preparation margins, making clinician-laboratory communication more efficient. AI is also used in manufacturing processes such as modeling, determining the most appropriate restoration type, and designing restorative morphology.[90] Revilla-León et al.[86] demonstrated that AI-assisted interjaw relationship recording using intraoral scanners is more accurate than recordings made without AI support.

There are some situations in prosthetic applications that require advanced experience. It has been reported that AI applications are used in some special situations, such as determining the tissue emergence profile in implant-supported prostheses, as well as planning the new crown to be made by taking into account the patient's tooth wear.[91,92] Lerner et al.[93] reported the 3-year survival and success rates of 99% and 91.3% for 106 implant-supported monolithic zirconia crowns they applied to 90 patients. This result is quite important because the researchers used AI support in all stages of their studies such as determining the emergence profile, designing the personal abutment and temporary prosthesis, and designing the margin line of the permanent crown.

Apart from these, AI applications are also used in prosthetic dental treatment applications like assessing tooth color, creating designs for removable prostheses, and predicting potential facial alterations caused by the use of these prostheses in patients.[94]

Artificial Intelligence Applications in Pedodontics

AI applications in pediatric dentistry provide assistance in preventive and therapeutic oral care until adulthood.[95] Research has demonstrated that AI systems can assist clinicians in utilizing behavioral guidance approaches, which are crucial in the field of pedodontics. Additionally, AI may assist in the early identification of plaque accumulation in primary teeth, early childhood caries (ECC), and dental anomalies.[95,96]

In their study, You et al.[36] reported that the DL model exhibited comparable efficacy to an experienced pedodontist in identifying plaque accumulation in primary teeth. The researchers stated that the advancement of the system would enable the utilization of AI not only by clinicians to manage children's everyday dental hygiene, but also by parents. Furthermore, the incorporation of ML in dentistry has been found to enhance precision and expedite outcomes. Consequently, this facilitates comprehension of the necessity for dental therapy and enables the evaluation of oral health by dentists, parents, and even children.[97,98]

Many general dentists may lack specific qualifications to diagnose mixed dentition in children. For this reason, the use of AI in pedodontics has also been evaluated to enhance radiographic imaging in detecting abnormal tooth eruptions and optimizing the identification of dental anomalies.[99-101] Ahn et al.[100] and Ha et al.[101] reported in their studies that the DL model provided a more accurate, faster, and clinically acceptable diagnosis than clinicians in detecting mesiodens across all dentition groups. Studies have indicated that with the support of AI in the detection of missing or excess teeth, clinicians can save time and energy while reaching more accurate treatment alternatives.[102,103]

In addition to environmental and behavioral factors, biological factors such as genetics also play a role in the formation of ECC.[104,105] In studies conducted; AI support has been used in the evaluation of the factors in the formation of ECC[105-107] and in the detection of ECC.[104,108] Research suggests that the advancement of these systems can have a positive impact on children's oral health by promoting early caries prevention strategies and encouraging parents to adopt healthier nutritional habits. Additionally, these systems can serve as a valuable tool for assessing the risk of caries.

Ensuring the elimination of child's fear and anxiety is crucial in pediatric dentistry. Hence, the child's behavior should serve as the basis for a effective and efficient therapy approach and a successful treatment outcome. AI-powered technologies like virtual reality and augmented reality enhance dental operations by providing immersive and engaging experiences that reduce fear and anxiety in children.[109] Research indicates that virtual reality decreases the average levels of anxiety and behavioral issues in children.[96,110,111] Nevertheless, it has been stated that AI functions mostly as an auxiliary instrument, due to the lacking ability to precisely respond the changing emotions and needs

of children in the same manner as a clinician and may be insufficient in non-verbal communication. Therefore, it has been emphasized that AI should be regarded as a tool that enhances the skills of dentists and should be utilized while maintaining interaction with patients focused on human needs.

Artificial Intelligence Applications in Orthodontics

AI applications in orthodontics have a wide range of uses in the fields of diagnosis, treatment planning, and clinical practice. A satisfactory orthodontic diagnosis relies on a series of analyses, like cephalometric analysis, dental analysis for molar relationships, tooth crowding, dental arch width, overjet and overbite, facial analysis, skeletal maturation determination, and upper airway obstruction assessment, to comprehensively evaluate patients' overall profile.[112] Visual configurations are crucial tools in the diagnostic and evaluative stages since they provide guidance for treatment and enhance patients' motivation for it. However, analyzing these visual configurations, like lateral cephalograms, intraoral and facial photographs manually is time-consuming and need intensive labor. Detecting the anatomical landmarks on lateral cephalograms is especially experience-dependent and may be inconsistent within and across orthodontists.[113] In recent years, with the advancements in AI technology, these analyses can be generated using AI-assisted software, which can utilize pictures, lateral and anteroposterior cephalograms or 3D models created by intraoral scanners.[114-116] CNN models are another instance where AI support is utilized in the diagnostic phase. The utilization of AI models has demonstrated the ability to detect crowding and malocclusion, that necessitates orthodontic treatment from intraoral photographs.[117,118] AI is also used for tooth detection in cleft lip and palate patients, and it demonstrated high overall sensitivity (0.98±0.03) and precision (0.96±0.04). It was found that the AI system is effective in detecting and numbering teeth in cleft lip and palate cases, but further refinement is required for improved accuracy, especially in the cleft region.[119]

Furthermore, there have been reported cases where AI programs have been used to assess the need for extraction treatment. Research has demonstrated that AI applications are highly capable and achieve exceptional accuracy when determining the need for tooth extraction.[114,115] AI has also made some progress in orthognathic surgery decision making; however, there is still a need for further improvement for more comprehensive and borderline cases.[113] Hence, it has been asserted that AI can serve as a supplementary instrument in clinical decision-making, and its potential in this area needs to be improved.

Study Limitations

AI has the potential to transform both daily life and professional activities, and its influence is growing across various industries, including dentistry.[120] Today, AI applications are widely used as supportive tools in different areas of dentistry. However, it presently lacks the ability to establish associations similar to the human brain and is only partially capable of making intricate decisions in a healthcare environment.[121] In uncertain situations, advanced information derived from a dentist's experience is crucial; these scenarios include performing physical examinations, integrating medical histories, evaluating aesthetic results, and facilitating discussions.[21,122] Effective patient-dentist communication requires a non-verbal evaluation of the patient's desires, concerns, and anticipations. This holds true despite ongoing discussions over the necessity of programming empathy into the algorithms that allow affective robots to replicate human emotions.[121,122]

Besides these, the adoption of new technologies often faces resistance. Dentists need to acquire specific skills to use AI safely and effectively in dental treatments, as the potential risks and challenges associated with AI must be carefully managed. Ethical, legal, and practical concerns, such as data privacy, algorithm transparency, and liability, present significant challenges that must be addressed to ensure the responsible and ethical implementation of AI in dentistry.[123] Continuous research in this field allows AI algorithms to be trained and refined over time. Despite these advancements, successfully integrating AI into everyday dental practice remains challenging due to limited data availability, a lack of rigorous scientific studies, and practical concerns about the value and application of these technologies.[119]

CONCLUSION

AI cannot yet replace clinical expertise, but its role in supporting traditional diagnostic and treatment methods is growing. Ongoing advancements, supported by collaboration and thorough validation, will further improve AI and ensure its safe and effective use in everyday dental practice.

MAIN POINTS

- Artificial intelligence (AI) enhances diagnostic accuracy and clinical outcomes in various dental specialties.
- Convolutional neural networks outperform traditional methods in analyzing dental radiographs.
- AI supports personalized treatment in prosthodontics, endodontics, pedodontics, periodontology, orthodontics, and oral surgery.
- Despite rapid progress, AI currently remains an adjunctive tool in dentistry.
- Integration of AI into routine dental practice requires further clinical studies and interdisciplinary collaboration.

Footnotes

Authorship Contributions

Design: S.E., Y.E.Ö., İ.Ö., Data Collection and/or Processing: S.E., Y.E.Ö., İ.Ö., B.D.K., B.B., Z.Ö.K., Literature Search: S.E., Y.E.Ö., İ.Ö., B.D.K., B.B., Writing: S.E., Y.E.Ö., İ.Ö., B.D.K., B.B., Z.Ö.K.

DISCLOSURES

Conflict of Interest: No conflict of interest was declared by the authors.

Financial Disclosure: The authors declared that this study had received no financial support.

REFERENCES

1. Kong SC, Cheung WM-Y, Zhang G. Evaluating artificial intelligence literacy courses for fostering conceptual learning, literacy and empowerment in university students: refocusing to conceptual building. Comput Human Behav Rep. 2022; 7(2): 100223.

2. Ossowska A, Kusiak A, Świetlik D. Artificial intelligence in dentistry-a narrative review. Int J Environ Res Public Health. 2022; 19(6): 3449.
3. Ahmed N, Abbasi MS, Zuberi F, Qamar W, Halim MSB, Maqsood A, et al. Artificial intelligence techniques: analysis, application, and outcome in dentistry-a systematic review. Biomed Res Int. 2021; 2021: 9751564.
4. Boztuna M, Firincioglulari M, Akkaya N, Orhan K. Segmentation of periapical lesions with automatic deep learning on panoramic radiographs: an artificial intelligence study. BMC Oral Health. 2024; 24(1): 1332.
5. Tandon D, Rajawat J. Present and future of artificial intelligence in dentistry. J Oral Biol Craniofac Res. 2020; 10(4): 391-6.
6. Hopfield JJ. Neural networks and physical systems with emergent collective computational abilities. Proc Natl Acad Sci U S A. 1982; 79(8): 2554-8.
7. Yu HJ, Cho SR, Kim MJ, Kim WH, Kim JW, Choi J. Automated skeletal classification with lateral cephalometry based on artificial intelligence. J Dent Res. 2020; 99(3): 249-56.
8. Khanagar SB, Al-Ehaideb A, Maganur PC, Vishwanathaiah S, Patil S, Baeshen HA, et al. Developments, application, and performance of artificial intelligence in dentistry - systematic review. J Dent Sci. 2021; 16(1): 508-22.
9. Chan S, Siegel EL. Will machine learning end the viability of radiology as a thriving medical specialty? Br J Radiol. 2019; 92(1094): 20180416.
10. White SC, Pharoah MJ. Oral radiology-E-book: principles and interpretation. Health Sciences; 2014
11. Tyndall DA. A primer and overview of the role of artificial intelligence in oral and maxillofacial radiology. Oral Surg Oral Med Oral Pathol Oral Radiol. 2024; 138(1): 112-7.
12. Putra RH, Doi C, Yoda N, Astuti ER, Sasaki K. Current applications and development of artificial intelligence for digital dental radiography. Dentomaxillofac Radiol. 2022; 51(1): 20210197.
13. Flores A, Rysavy S, Enciso R, Okada K, editors. Non-invasive differential diagnosis of dental periapical lesions in cone-beam CT. In: 2009 IEEE International Symposium on Biomedical Imaging: From Nano to Macro. IEEE; 2009.
14. 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.
15. Krois J, Ekert T, Meinhold L, Golla T, Kharbot B, Wittemeier A, et al. Deep learning for the radiographic detection of periodontal bone loss. Sci Rep. 2019; 9(1): 8495.
16. Davies A, Mannocci F, Mitchell P, Andiappan M, Patel S. The detection of periapical pathoses in root-filled teeth using single and parallax periapical radiographs versus cone beam computed tomography-a clinical study. Int Endod J. 2015; 48(6): 582-92.
17. Tuzoff DV, Tuzova LN, Bornstein MM, Krasnov AS, Kharchenko MA, Nikolenko SI, et al. Tooth detection and numbering in panoramic radiographs using convolutional neural networks. Dentomaxillofac Radiol. 2019; 48(4): 20180051.
18. K›l›c MC, Bayrakdar IS, Çelik Ö, Bilgir E, Orhan K, Ayd›n OB, et al. Artificial intelligence system for automatic deciduous tooth detection and numbering in panoramic radiographs. Dentomaxillofac Radiol. 2021; 50(6): 20200172.
19. Chen H, Zhang K, Lyu P, Li H, Zhang L, Wu J, et al. A deep learning approach to automatic teeth detection and numbering based on object detection in dental periapical films. Sci Rep. 2019; 9(1): 3840.
20. Orhan K, Bayrakdar IS, Ezhov M, Kravtsov A, Özyürek T. Evaluation of artificial intelligence for detecting periapical pathosis on cone-beam computed tomography scans. Int Endod J. 2020; 53(5): 680-9.
21. Fukuda M, Inamoto K, Shibata N, Ariji Y, Yanashita Y, Kutsuna S, et al. Evaluation of an artificial intelligence system for detecting vertical root fracture on panoramic radiography. Oral Radiol. 2020; 36(4): 337-43.
22. Kise Y, Ikeda H, Fujii T, Fukuda M, Ariji Y, Fujita H, et al. Preliminary study on the application of a deep learning system to the diagnosis of Sjögren's syndrome on CT images. Dentomaxillofac Radiol. 2019; 48(6): 20190019.
23. Ariji Y, Sugita Y, Nagao T, Nakayama A, Fukuda M, Kise Y, et al. CT evaluation of extranodal extension of cervical lymph node metastases in patients with oral squamous cell carcinoma using deep learning classification. Oral Radiol. 2020; 36(2): 148-55.
24. Lee JS, Adhikari S, Liu L, Jeong HG, Kim H, Yoon SJ. Osteoporosis detection in panoramic radiographs using a deep convolutional neural network-based computer-assisted diagnosis system: a preliminary study. Dentomaxillofac Radiol. 2019; 48(1): 20170344.
25. Lee KS, Jung SK, Ryu JJ, Shin SW, Choi J. Evaluation of transfer learning with deep convolutional neural networks for screening osteoporosis in dental panoramic radiographs. J Clin Med. 2020; 9(2): 392.
26. Miragall MF, Knoedler S, Kauke-Navarro M, Saadoun R, Grabenhorst A, Grill FD, et al. Face the future-artificial intelligence in oral and maxillofacial surgery. J Clin Med. 2023; 12(21): 6843.
27. Vinayahalingam S, Xi T, Bergé S, Maal T, de Jong G. Automated detection of third molars and mandibular nerve by deep learning. Sci Rep. 2019; 9(1): 9007.
28. Zhang W, Li J, Li ZB, Li Z. Predicting postoperative facial swelling following impacted mandibular third molars extraction by using artificial neural networks evaluation. Sci Rep. 2018; 8(1): 12281.
29. Park W, Schwendicke F, Krois J, Huh JK, Lee JH. Identification of dental implant systems using a large-scale multicenter dataset. J Dent Res. 2023; 102(7): 727-33.
30. Kurt Bayrakdar S, Orhan K, Bayrakdar IS, Bilgir E, Ezhov M, Gusarev M, et al. A deep learning approach for dental implant planning in cone-beam computed tomography images. BMC Med Imaging. 2021; 21(1): 86.
31. Ilhan B, Lin K, Guneri P, Wilder-Smith P. Improving oral cancer outcomes with imaging and artificial intelligence. J Dent Res. 2020; 99(3): 241-8.
32. Halicek M, Lu G, Little JV, Wang X, Patel M, Griffith CC, et al. Deep convolutional neural networks for classifying head and neck cancer using hyperspectral imaging. J Biomed Opt. 2017; 22(6): 60503.
33. Poedjiastoeti W, Suebnukarn S. Application of Convolutional neural network in the diagnosis of jaw tumors. Healthc Inform Res. 2018; 24(3): 236-41.
34. Troiano G, Fanelli F, Rapani A, Zotti M, Lombardi T, Zhurakivska K, et al. Can radiomic features extracted from intra-oral radiographs predict physiological bone remodelling around dental implants? A hypothesis-generating study. J Clin Periodontol. 2023; 50(7): 932-41.
35. Troiano G, Nibali L, Petsos H, Eickholz P, Saleh MHA, Santamaria P, et al. Development and international validation of logistic regression and machine-learning models for the prediction of 10-year molar loss. J Clin Periodontol. 2023; 50(3): 348-57.
36. You W, Hao A, Li S, Wang Y, Xia B. Deep learning-based dental plaque detection on primary teeth: a comparison with clinical assessments. BMC Oral Health. 2020; 20(1): 141.
37. Alalharith DM, Alharthi HM, Alghamdi WM, Alsenbel YM, Aslam N, Khan IU, et al. A deep learning-based approach for the detection of early signs of gingivitis in orthodontic patients using faster region-based convolutional neural networks. Int J Environ Res Public Health. 2020; 17(22): 8447.
38. Moriyama Y, Lee C, Date S, Kashiwagi Y, Narukawa Y, Nozaki K, et al. A MapReduce-like deep learning model for the depth estimation of periodontal pockets. HEALTHINF. 2019.

39. Danks RP, Bano S, Orishko A, Tan HJ, Moreno Sancho F, D'Aiuto F, et al. Automating periodontal bone loss measurement via dental landmark localisation. Int J Comput Assist Radiol Surg. 2021; 16(7): 1189-99.

40. Ozden FO, Özgönenel O, Özden B, Aydogdu A. Diagnosis of periodontal diseases using different classification algorithms: a preliminary study. Niger J Clin Pract. 2015; 18(3): 416-21.

41. Mameno T, Wada M, Nozaki K, Takahashi T, Tsujioka Y, Akema S, et al. Predictive modeling for peri-implantitis by using machine learning techniques. Sci Rep. 2021; 11(1): 11090.

42. Wang CW, Hao Y, Di Gianfilippo R, Sugai J, Li J, Gong W, et al. Machine learning-assisted immune profiling stratifies peri-implantitis patients with unique microbial colonization and clinical outcomes. Theranostics. 2021; 11(14): 6703-16.

43. Nakano Y, Takeshita T, Kamio N, Shiota S, Shibata Y, Suzuki N, et al. Supervised machine learning-based classification of oral malodor based on the microbiota in saliva samples. Artif Intell Med. 2014; 60(2): 97-101.

44. Shimpi N, McRoy S, Zhao H, Wu M, Acharya A. Development of a periodontitis risk assessment model for primary care providers in an interdisciplinary setting. Technol Health Care. 2020; 28(2): 143-54.

45. Bashir NZ, Rahman Z, Chen SL. Systematic comparison of machine learning algorithms to develop and validate predictive models for periodontitis. J Clin Periodontol. 2022; 49(10): 958-69.

46. Xiang J, Huang W, He Y, Li Y, Wang Y, Chen R. Construction of artificial neural network diagnostic model and analysis of immune infiltration model for periodontitis. Front Genet. 2022; 13: 1041524.

47. Lakshmi T, Dheeba J. Digital decision making in dentistry: analysis and prediction of periodontitis using machine learning approach. Int J Next Generation Comput. 2022; 13(3).

48. Uzun Saylan BC, Baydar O, Yeflilova E, Kurt Bayrakdar S, Bilgir E, Bayrakdar ‹fi, et al. Assessing the Effectiveness of Artificial Intelligence Models for Detecting Alveolar Bone Loss in Periodontal Disease: A Panoramic Radiograph Study. Diagnostics (Basel). 2023; 13(10): 1800.

49. Shankarapillai R, Mathur LK, Nair MA, George R. Periodontitis risk assessment using two artificial neural network algorithms-a comparative study. Int J Dental Clin. 2012; 4: 17–21.

50. Aminoshariae A, Kulild J, Nagendrababu V. Artificial intelligence in endodontics: current applications and future directions. J Endod. 2021; 47(9): 1352-7.

51. Tumbelaka BY, Oscandar F, Baihaki FN, Sitam S, Rukmo M. Identification of pulpitis at dental X-ray periapical radiography based on edge detection, texture description, and artificial neural networks. Saudi Endod J. 2014; 4(3): 115-21.

52. Zheng L, Wang H, Mei L, Chen Q, Zhang Y, Zhang H. Artificial intelligence in digital cariology: a new tool for the diagnosis of deep caries and pulpitis using convolutional neural networks. Ann Transl Med. 2021; 9(9): 763.

53. Saghiri MA, Asgar K, Boukani KK, Lotfi M, Aghili H, Delvarani A, et al. A new approach for locating the minor apical foramen using an artificial neural network. Int Endod J. 2012; 45(3): 257-65.

54. Saghiri MA, Garcia-Godoy F, Gutmann JL, Lotfi M, Asgar K. The reliability of artificial neural network in locating minor apical foramen: a cadaver study. J Endod. 2012; 38(8): 1130-4.

55. Pauwels R, Brasil DM, Yamasaki MC, Jacobs R, Bosmans H, Freitas DQ, et al. Artificial intelligence for detection of periapical lesions on intraoral radiographs: comparison between convolutional neural networks and human observers. Oral Surg Oral Med Oral Pathol Oral Radiol. 2021; 131(5): 610-6.

56. Setzer FC, Shi KJ, Zhang Z, Yan H, Yoon H, Mupparapu M, et al.Artificial intelligence for the computer-aided detection of periapical lesions in cone-beam computed tomographic images. J Endod. 2020; 46(7): 987-93.

57. Ekert T, Krois J, Meinhold L, Elhennawy K, Emara R, Golla T, et al. Deep learning for the radiographic detection of apical lesions. J Endod. 2019; 45(7): 917-22.

58. Kositbowornchai S, Plermkamon S, Tangkosol T. Performance of an artificial neural network for vertical root fracture detection: an ex vivo study. Dent Traumatol. 2013; 29(2): 151-5.

59. Mikrogeorgis G, Eirinaki E, Kapralos V, Koutroulis A, Lyroudia K, Pitas I. Diagnosis of vertical root fractures in endodontically treated teeth utilising Digital subtraction radiography: a case series report. Aust Endod J. 2018; 44(3): 286-91.

60. Johari M, Esmaeili F, Andalib A, Garjani S, Saberkari H. Detection of vertical root fractures in intact and endodontically treated premolar teeth by designing a probabilistic neural network: an ex vivo study. Dentomaxillofac Radiol. 2017; 46(2): 20160107.

61. Sherwood AA, Sherwood AI, Setzer FC, Shamili JV, John C, Schwendicke F. A deep learning approach to segment and classify C-shaped canal morphologies in mandibular second molars using cone-beam computed tomography. J Endod. 2021; 47(12): 1907-16.

62. Jeon SJ, Yun JP, Yeom HG, Shin WS, Lee JH, Jeong SH, et al. Deep-learning for predicting C-shaped canals in mandibular second molars on panoramic radiographs. Dentomaxillofac Radiol. 2021; 50(5): 20200513.

63. Yang S, Lee H, Jang B, Kim KD, Kim J, Kim H, et al. Development and validation of a visually explainable deep learning model for classification of C-shaped canals of the mandibular second molars in periapical and panoramic dental radiographs. J Endod. 2022; 48(7): 914-21.

64. Mallishery S, Chhatpar P, Banga KS, Shah T, Gupta P. The precision of case difficulty and referral decisions: an innovative automated approach. Clin Oral Investig. 2020; 24(6): 1909-15.

65. Campo L, Aliaga IJ, De Paz JF, García AE, Bajo J, Villarubia G, et al. Retreatment predictions in odontology by means of CBR systems. Comput Intell Neurosci. 2016; 2016: 7485250.

66. Herbst CS, Schwendicke F, Krois J, Herbst SR. Association between patient-, tooth- and treatment-level factors and root canal treatment failure: a retrospective longitudinal and machine learning study. J Dent. 2022; 117: 103937.

67. Hasan HA, Saad FH, Ahmed S, Mohammed N, Farook TH, Dudley J. Experimental validation of computer-vision methods for the successful detection of endodontic treatment obturation and progression from noisy radiographs. Oral Radiol. 2023; 39(4): 683-98.

68. Peeters HH, Judith ET, Silitonga FY, Zuhal LR. Visualizing the velocity fields and fluid behavior of a solution using artificial intelligence during EndoActivator activation. Majalah Kedokteran Gigi. 2022; 55(3): 125-9.

69. Peeters HH, Silitonga F, Zuhal L. Application of artificial intelligence in a visual-based fluid motion estimator surrounding a vibrating Eddy tip. G Ital Endodonzia. 2022; 36(1).

70. Aminoshariae A, Nosrat A, Nagendrababu V, Dianat O, Mohammad-Rahimi H, O'Keefe AW, Setzer FC. Artificial intelligence in endodontic education. J Endod. 2024; 50(5): 562-78.

71. Lahoud P, EzEldeen M, Beznik T, Willems H, Leite A, Van Gerven A, et al. Artificial Intelligence for fast and accurate 3-dimensional tooth segmentation on cone-beam computed tomography. J Endod. 2021; 47(5): 827-35.

72. Schwendicke F, Samek W, Krois J. Artificial intelligence in dentistry: chances and challenges. J Dent Res. 2020; 99(7):769-74.

73. Revilla-León M, Gómez-Polo M, Vyas S, Barmak AB, Özcan M, Att W, et al. Artificial intelligence applications in restorative dentistry: a systematic review. J Prosthet Dent. 2022; 128(5): 867-75.

74. Mendonça EA. Clinical decision support systems: perspectives in dentistry. J Dent Educ. 2004; 68(6): 589-97.

75. Khanna S. Artificial intelligence: contemporary applications and future compass. Int Dent J. 2010; 60(4): 269-72.

76. Bayraktar Y, Ayan E. Diagnosis of interproximal caries lesions with deep convolutional neural networks in digital bitewing radiographs. Clin Oral Investig. 2022; 26(1): 623-32.

77. Lee JH, Kim DH, Jeong SN, Choi SH. Detection and diagnosis of dental caries using a deep learning-based convolutional neural network algorithm. J Dent. 2018; 77: 106-11.

78. Cha JY, Yoon HI, Yeo IS, Huh KH, Han JS. Peri-Implant Bone Loss Measurement Using a Region-Based Convolutional Neural Network on Dental Periapical Radiographs. J Clin Med. 2021; 10(5): 1009.

79. Abdalla-Aslan R, Yeshua T, Kabla D, Leichter I, Nadler C. An artificial intelligence system using machine learning for automatic detection and classification of dental restorations in panoramic radiography. Oral Surg Oral Med Oral Pathol Oral Radiol. 2020; 130(5): 593-602.

80. Krois J, Garcia Cantu A, Chaurasia A, Patil R, Chaudhari PK, et al. Generalizability of deep learning models for dental image analysis. Sci Rep. 2021; 11(1): 6102.

81. Schwendicke F, Elhennawy K, Paris S, Friebertshäuser P, Krois J. Deep learning for caries lesion detection in near-infrared light transillumination images: a pilot study. J Dent. 2020; 92: 103260.

82. Ahmed WM, Azhari AA, Fawaz KA, Ahmed HM, Alsadah ZM, Majumdar A, et al. Artificial intelligence in the detection and classification of dental caries. J Prosthet Dent. 2025; 133(5): 1326-32.

83. Engels P, Meyer O, Schönewolf J, Schlickenrieder A, Hickel R, Hesenius M, et al. Automated detection of posterior restorations in permanent teeth using artificial intelligence on intraoral photographs. J Dent. 2022; 121: 104124.

84. Schlickenrieder A, Meyer O, Schönewolf J, Engels P, Hickel R, Gruhn V, et al. Automatized detection and categorization of fissure sealants from intraoral digital photographs using artificial intelligence. Diagnostics (Basel). 2021; 11(9): 1608.

85. Krishnegowda SC, Jaganath BM, Rudranaik S, Harnad AB. Artificial intelligence in restorative dentistry and endodontics—a short review. Indian J Clin Res Dent. 2023; 4: 12-5.

86. Revilla-León M, Gómez-Polo M, Barmak AB, Kois JC, Alonso Pérez-Barquero J. Accuracy of an artificial intelligence-based program for locating the maxillomandibular relationship of scans acquired by using intraoral scanners. J Prosthet Dent. 2024: S0022-3913(24)00053-2

87. Tabatabaian F, Vora SR, Mirabbasi S. Applications, functions, and accuracy of artificial intelligence in restorative dentistry: a literature review. J Esthet Restor Dent. 2023; 35(6): 842-59.

88. Mangano F, Margiani B, Admakin O. A novel full-digital protocol (SCAN-PLAN-MAKE-DONE®) for the design and fabrication of implant-supported monolithic translucent zirconia crowns cemented on customized hybrid abutments: a retrospective clinical study on 25 patients. Int J Environ Res Public Health. 2019; 16(3): 317.

89. Al Hendi KD, Alyami MH, Alkahtany M, Dwivedi A, Alsaqour HG. Artificial intelligence in prosthodontics. Bioinformation. 2024; 20(3): 238-42.

90. Cabanes-Gumbau G, Palma JC, Kois JC, Revilla-León M. Transferring the tooth preparation finish line on intraoral digital scans to dental software programs: a dental technique. J Prosthet Dent. 2023; 130(4): 439–43.

91. Joda T, Gallucci GO, Wismeijer D, Zitzmann NU. Augmented and virtual reality in dental medicine: a systematic review. Comput Biol Med. 2019; 108: 93–100.

92. Bernauer SA, Zitzmann NU, Joda T. The use and performance of artificial intelligence in prosthodontics: a systematic review. Sensors (Basel). 2021; 21(19): 6628.

93. 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.

94. Bonny T, Al Nassan W, Obaideen K, Al Mallahi MN, Mohammad Y, El-Damanhoury HM. Contemporary role and applications of artificial intelligence in dentistry. F1000Res. 2023; 12: 1179.

95. Acharya S, Godhi BS, Saxena V, Assiry AA, Alessa NA, Dawasaz AA, et al. Role of artificial intelligence in behavior management of pediatric dental patients-a mini review. J Clin Pediatr Dent. 2024; 48(3): 24-30.

96. Vishwanathaiah S, Fageeh H, Khanagar S, Maganur P. Artificial intelligence: its uses and applications in pediatric dentistry-a review. Biomedicines. 2023; 11(3): 788.

97. Klingberg G, Sillén R, Norén JG. Machine learning methods applied to dental fear and behavior management problems in children. Acta Odontol Scand. 1999; 57(4): 207-15.

98. Vellappally S, Al Kheraif AA, Anil S, Wahba AA. IoT medical tooth-mounted sensor for monitoring teeth and food level using bacterial optimization along with adaptive deep learning neural network. Measurement. 2019; 135: 672-7.

99. Zhu H, Yu H, Zhang F, Cao Z, Wu F, Zhu F. Automatic segmentation and detection of ectopic eruption of first permanent molars on panoramic radiographs based on nnU-Net. Int J Paediatr Dent. 2022; 32(6): 785-92.

100. Ahn Y, Hwang JJ, Jung YH, Jeong T, Shin J. Automated mesiodens classification system using deep learning on panoramic radiographs of children. Diagnostics. 2021; 11(8): 1477.

101. Ha EG, Jeon KJ, Kim YH, Kim JY, Han SS. Automatic detection of mesiodens on panoramic radiographs using artificial intelligence. Sci Rep. 2021; 11(1): 23061.

102. Mine Y, Iwamoto Y, Okazaki S, Nakamura K, Takeda S, Peng TY, et al. Detecting the presence of supernumerary teeth during the early mixed dentition stage using deep learning algorithms: A pilot study. Int J Paediatr Dent. 2022; 32(5): 678-85.

103. Kaya E, Gunec HG, Gokyay SS, Kutal S, Gulum S, Ates HF. Proposing a CNN method for primary and permanent tooth detection and enumeration on pediatric dental radiographs. J Clin Pediatr Dent. 2022; 46(4): 293-8.

104. Park YH, Kim SH, Choi YY. Prediction models of early childhood caries based on machine learning algorithms. Int J Environ Res Public Health. 2021; 18(16): 8613.

105. Zaorska K, Szczapa T, Borysewicz-Lewicka M, Nowicki M, Gerreth K. Prediction of early childhood caries based on single nucleotide polymorphisms using neural networks. Genes. 2021; 12(4): 462.

106. Koopaie M, Salamati M, Montazeri R, Davoudi M, Kolahdooz S. Salivary cystatin S levels in children with early childhood caries in comparison with caries-free children: statistical analysis and machine learning. BMC Oral Health. 2021; 21(1): 650.

107. Pang L, Wang K, Tao Y, Zhi Q, Zhang J, Lin H. A new model for caries risk prediction in teenagers using a machine learning algorithm based on environmental and genetic factors. Front Genet. 2021; 12: 636867.

108. Karhade DS, Roach J, Shrestha P, Simancas-Pallares MA, Ginnis J, Burk ZJS, et al. An Automated Machine Learning Classifier for Early Childhood Caries. Pediatr Dent. 2021; 43(3): 191-7.

109. Reeves R, Curran D, Gleeson A, Hanna D. A meta-analysis of the efficacy of virtual reality and in vivo exposure therapy as psychological interventions for public speaking anxiety. Behav Modif. 2022; 46(4): 937-65.

110. Evans C, Moonesinghe R. Virtual reality in pediatric anesthesia: a toy or a tool. Pediatr Anesth. 2020; 30(4).

111. Böhnlein J, Altegoer L, Muck NK, Roesmann K, Redlich R, Dannlowski U, et al. Factors influencing the success of exposure therapy for specific phobia: a systematic review. Neurosci Biobehav Rev. 2020; 108: 796-820.

112. Proffit WR, Fields HW, Larson B, Sarver DM. Contemporary Orthodontics-e-Book. Amsterdam: Elsevier Health Sciences; 2018.

113. Liu J, Zhang C, Shan Z. Application of Artificial intelligence in orthodontics: current state and future perspectives. Healthcare (Basel). 2023; 11(20): 2760.

114. Kim MJ, Liu Y, Oh SH, Ahn HW, Kim SH, Nelson G. Evaluation of a multi-stage convolutional neural network-based fully automated landmark identification system using cone-beam computed tomographysynthesized posteroanterior cephalometric images. Korean J Orthod. 2021; 51(2): 77-85.

115. Takeda S, Mine Y, Yoshimi Y, Ito S, Tanimoto K, Murayama T. Landmark annotation and mandibular lateral deviation analysis of posteroanterior cephalograms using a convolutional neural network. J Dent Sci. 2021; 16(3): 957-63.

116. Fawaz P, Sayegh PE, Vannet BV. What is the current state of artificial intelligence applications in dentistry and orthodontics? J Stomatol Oral Maxillofac Surg. 2023; 124(5): 101524.

117. Ryu J, Kim YH, Kim TW, Jung SK. Evaluation of artificial intelligence model for crowding categorization and extraction diagnosis using intraoral photographs. Sci Rep. 2023; 13(1): 5177.

118. Talaat S, Kaboudan A, Talaat W, Kusnoto B, Sanchez F, Elnagar MH, et al. The validity of an artificial intelligence for assessment of orthodontic treatment need from clinical images. Semin Orthod. 2021; 27(2): 164-71.

119. Arslan C, Yucel NO, Kahya K, Sunal Akturk E, Germec Cakan D. Artificial intelligence for tooth detection in cleft lip and palate patients. Diagnostics (Basel). 2024; 14(24): 2849.

120. Păvăloaia V-D, Necula S-C. Artificial intelligence as a disruptive technology-a systematic literature review. Electronics. 2023; 12(5): 1102.

121. Boreak N. Effectiveness of artificial intelligence applications designed for endodontic diagnosis, decision-making, and prediction of prognosis: a systematic review. J Contemp Dent Pract. 2020; 21(8): 926-34.

122. Dennis D, Suebnukarn S, Heo MS, Abidin T, Nurliza C, Yanti N, et al. Artificial intelligence application in endodontics: a narrative review. Imaging Sci Dent. 2024; 54(4): 305-12.

123. Pethani F. Promises and perils of artificial intelligence in dentistry. Aust Dent J. 2021; 66(2): 124-135.