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Artificial Intelligence in Dental Caries Detection: Current Advances, Challenges, and Future Perspectives

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Abstract

Dental caries remains one of the most prevalent chronic oral diseases worldwide, posing a significant burden on public health systems and affecting individuals across all age groups. Conventional diagnostic approaches, including visual-tactile examination and radiographic assessment, are often limited by subjectivity, variability, and reduced sensitivity in detecting early-stage lesions. In recent years, artificial intelligence (AI), particularly machine learning and deep learning techniques, has emerged as a promising tool to enhance the accuracy and efficiency of caries detection. This review provides a comprehensive overview of current advancements in AI applications for dental caries diagnosis, focusing on deep learning models such as convolutional neural networks and their role in analyzing dental radiographs and clinical images. The review highlights the clinical applications of AI in detecting proximal, occlusal, and early enamel lesions, as well as its potential in caries risk prediction and integration into digital dental workflows. Furthermore, the advantages of AI, including improved diagnostic consistency, early detection, and workflow optimization, are discussed alongside key challenges such as data quality, lack of standardization, ethical concerns, and limited interpretability. Emerging trends, including explainable AI, teledentistry integration, and real-time chairside diagnostic tools, are also explored. Overall, AI demonstrates substantial potential to transform caries diagnosis and support precision dentistry; however, further validation, standardization, and

clinical integration are essential for its widespread adoption in routine dental practice.

INTRODUCTION

1.1 Global Burden of Dental Caries

Dental caries is considered as one of the most common chronic diseases of the whole globe in terms of its occurrence among all ages and socioeconomic groups. Untreated caries of permanent teeth in the mouth is reported to be among the most prevalent conditions in terms of oral morbidity and decreased quality of life according to global health estimates (1,2). This is especially overburdening in low- and middle-income nations, where access to preventive and restorative dental care is limited, and this aspect contributes to the aggravation of the disease (3). Early childhood caries has remained one of the predominant public health issues in children, regularly resulting in suffering, infection, and poor nutritional condition (4). In spite of the world improving on preventive measures, the incidences of dental caries have not reduced significantly, thus, necessitating the investigation of better methods of diagnosis and management (5).

Limitations of Conventional Diagnostic Methods

The conventional approaches to the diagnosis of dental caries involve mostly the use of visual-tactile inspection and radiographic analysis; the bitewing and periapical radiographs. Although these methods are common in clinical practice, they are also subjective in nature and are also reliant on experience and competency of the clinician (6). Enamel lesions especially non-cavitated caries are usually hard to detect by conventional methods thus becoming underdiagnosed or untreated (7). Radiographies, however useful, do not detect the presence of incipient lesions because of poor sensitivity and problems of variability in image interpretation (8). Also, the low levels of exposure to ionizing radiations are of concern as far as repeating imaging is concerned, particularly in cases of pediatrics (9). Such restrictions emphasize the need to have more reliable, objective and sensitive diagnostic tools.

1.2 **The rise of Artificial Intelligence in Dentistry**

Machine learning and deep learning approaches to artificial intelligence (AI) has become a disruptive technology in the medical field, dentistry included. Recently, AI-based solutions have proven to have a lot of potential in carious lesion identification in dental images with high accuracy (10,11). CNNs are a type of deep learning model and are widely used to analyze dental radiographs to determine caries (12). Such systems are able to handle big data, identify intricate patterns and deliver stable diagnostics results thus minimizing the human factor (13). The use of AI in dental diagnostics signifies a change in the direction of evidence-based and precision-oriented clinical decision-making (14).

1.3 Aim and Scope of the Review

The purpose of this review is to give a broad overview of the existing progress on artificial intelligence in dental caries detection. It discusses the principles of AI used, clinical applications, benefits, and shortcomings of AI, and the future of AI-based diagnostics in dentistry due to emerging trends. Having critically examined the current events, the review will aim at identifying the potential of AI to improve diagnostic accuracy, early detection, and patient outcomes as well as solve the current challenges and research gaps (15).

2. Fundamentals of Artificial Intelligence in Dentistry

3. **2.1 Overview of Artificial Intelligence, Machine Learning, and Deep Learning**

Artificial intelligence (AI) can be defined as the creation of computer systems that can carry out functions that the human intellect is usually tasked to execute, such as pattern recognition, decision-making, and problem-solving. In AI, machine learning (ML) allows systems to acquire knowledge through data, and is unable to be explicitly programmed, whereas deep learning (DL), a form of machine learning, trains multi-layered neural networks to recognize complex patterns in massive data (16,17). Such technologies have received considerable attention in the field of dentistry given the fact that they can analyze diagnostic pictures and clinical data to a great extent. Image-based tasks in particular, caries detection, are best served by deep learning models with convolutional neural networks (CNNs) being the most appropriate models (18). The hierarchical nature of the feature extraction of the DL enables it to identify small variations in the structure of teeth that offline observers might not be able to notice (19).

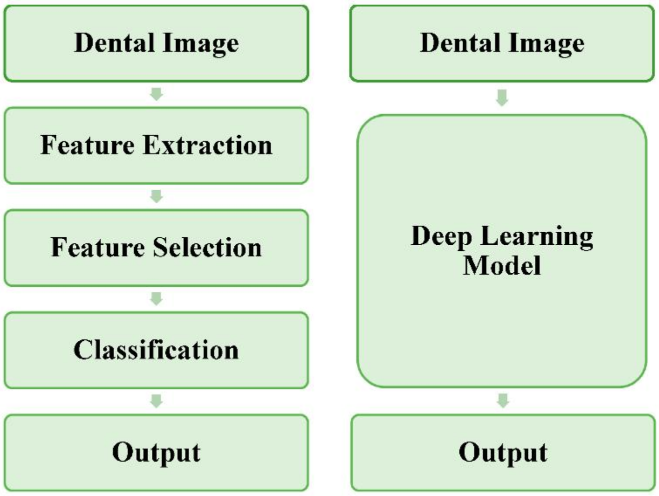

Figure 1. Primary Methods and Algorithms in Artificial-Intelligence-Based Dental Image Analysis

2.2 AI Model types applied in dental imaging

A number of AI models are used in detecting caries in dental imaging. The most commonly used ones are convolutional neural networks (CNNs), which are better in image classification and segmentation tasks (20). These models are able to learn visual features hierarchy of spaces and radiographic images and photographic images automatically. They have also used artificial neural networks (ANNs) and support vector machines (SVMs) especially in previous research in order to classify and predict (21). Further refined architectures, including deep residual networks (ResNet) and U-Net models, have encouraged the level of accuracy in the lesion-detecting and localizing (22). These models are trained using annotated data sets with expert-labeled images instructing the learning to allow the system to distinguish between healthy and carious tissues (23).

2.3 Data Sources for AI in Caries Detection

The quality and variety of input data are crucial to the effectiveness of AI systems in the field of dentistry. Intraoral radiographs, especially bitewing radiographs, form a common part of the data used in caries detection as the source of data and these are regarded as the gold standard of detecting proximal caries (24). There is also the use of periapical radiographs and cone-beam computed tomography (CBCT) images to conduct a more detailed structural analysis (25). Furthermore, the digital scanning data and intraoral photographic images have been added to AI models to detect the presence of occlusal and early enamel lesions (26). Training powerful AI systems is heavily dependent on the use of large, heavily annotated datasets, but the variability in imaging protocols and annotation standards can affect model performance (27). The quality, standardization, and diversity of data are also critical to ensure the AI-based caries detection systems are more generalized and have clinical applicability (28).

3. AI Techniques for Dental Caries Detection

3.1 Deep Learning-Based Detection (Convolutional Neural Networks)

The most effective caries detection method has been based on deep learning and especially the convolutional neural networks (CNNs), because it is more effective in reading a picture. CNNs can automatically extract hierarchical features of input images and thus detect fine radiographic changes in relation to caries in the mouth (29). These models have been effectively used in bitewing radiographs and periapical radiographs and have shown diagnostic accuracy that is comparable and, in some cases, better than experienced clinicians (30). Further improvement of the architectures of CNN (i.e., ResNet, DenseNet) facilitates better feature reconstructing and classification and enables the detection of earlier lesions (31). Moreover, CNN-based systems may be used to undertake not only classification but also localization of carious lesions not only their presence but also the exact position (32).

3.2 Image Processing and Feature Extraction Approaches

Before the deep learning methodology became a common practice, caries detection was usually done through traditional image processing methods. Such methods include pre-processing procedures that include noise reduction, contrast enhancement, and segmentation, then extraction of features that are either manual or semi-automatic (33). The properties that can be distinguished include the analysis of texture, intensity, and edge information to distinguish between healthy and demineralized tooth structures (34). Classification is then performed by use of the support vectors machines (SVMs), decision trees among other machine learning algorithms based on these extracted features (35). Despite the mediocre results of these methods, they are constrained by the fact that they use handcrafted features and are less adaptable than deep learning models (36).

3.3 Automated vs. Semi-Automated Diagnostic Systems

The caries detection systems based on AI can be divided into fully automated and semi-automated solutions. Fully automated systems need minimum human intervention and can process and analyses images on their own hence giving real time outputs of diagnostic results (37). Such systems are especially beneficial in clinical environments with a high rate of throughput where efficiency and consistency is crucial. The semi-automated systems, in contrast, are systems that require some level of clinician intervention, like region-of-interest selection or result manual verification (38). Although semi-automated methods can have more control and interpretability, they are typically more time-consuming and can also be prone to human variance as well (39). The decision to use one of these systems or the other is determined by the needs of clinical practice, the infrastructure available, and the degree of confidence in the AI-generated results.

3.4 Performance Metrics (Accuracy, Sensitivity, Specificity, AUC)

The analysis of AI models to detect caries is based on a number of standard performance measurements. Sensitivity (recall) represents the quantity of the capacity to detect carious lesions correctly, and specificity is represented by the capacity to detect non-carious surfaces correctly (40). The region beneath the receiver operating characteristic curve (AUC-ROC) is popular in terms of evaluating the entire diagnostic performance of AI systems and is a holistic approach of evaluating the sensitivity and specificity at varying thresholds (41). The sensitivity and specificity rates of high-performing AI models have been reported to be above 8590, which signifies that they can be used in clinical practice (42). Nevertheless, the heterogeneity of datasets, schemes of validation, and study designs might affect the outcomes that are reported, which is why the standard evaluation frameworks are necessary (43).

4. Applications of AI in Caries Diagnosis

4.1 Detection of Proximal Caries on Bitewing Radiographs

The caries detection in proximal caries using the bitewing radiographs is so far one of the most developed applications of artificial intelligence in the field of dentistry. The proximity of the lesions can be hard to diagnose by the naked eye as they lie between the teeth. Convolutional neural networks and other AI models have proved to be very accurate in the recognition of these lesions through the examination of radiographic patterns and changes in mineral density (44). Research has indicated that AI-aided interpretation of bitewing radiographs may improve diagnostic sensitivity with acceptable specificity and consequently aid clinicians in an early diagnosis of lesions (45). In addition, AI can minimize inter- and intra-observer variability, and the results of diagnosis can become more consistent (46).

4.2 Occlusal and Early Enamel Lesion Detection

Occlusal caries and the early lesions of enamel are a clinical dilemma because of an insidious presentation and minimal radiographic ability. The use of an AI system based on intraoral images and sophisticated imaging modalities have demonstrated potential in the detection of these lesions at an early phase (47). Deep learning models are capable of recognizing the slightest variations in the texture and color on the enamel that could be a sign of the initial demineralization (48). Timely diagnosis is essential in carrying out preventive and least invasive treatment measures, and AI can greatly enhance the results as it can simplify the process of diagnosis (49).

4.3 Caries Risk Assessment and Prediction Models

In addition to lesion identification, AI has been used more frequently to assess risks of caries and predictive modeling. Machine learning algorithms have the ability to predict the risk of a person developing dental caries based on a combination of clinical, behavioral, and demographic data (50). Such models include diet, oral-hygiene practice, exposure to fluoride, and past experience with caries to create individual risk profiles (51). Predictive analytics can help clinicians to create specific preventative measures and streamline patient care which is in line with the concepts of personalized and preventive dentistry (52).

4.4 Integration with Digital Dentistry and Clinical Workflows

With the adoption of AI in digital dentistry, there has been easy integration of diagnostic instruments into the standard clinical practices. Dental imaging systems can be integrated with AI-based software, which will be able to analyze radiographs real-time and provide feedback to clinicians (53). This combination improves efficiency, decreases diagnostic time and assists in decision-making when a patient has consulted a physician (54). Moreover, AI systems can be integrated with electronic health records and digital treatment planning tools to formulate holistic and data-driven clinical settings (55). With the ongoing development of digital dentistry, the field of AI application in improving the precision of diagnoses and optimizing workflow is to grow, no doubt, further (56).

Figure 1. All-Digital Workflow for Enhanced Care: Precision, Comfort, and Effortless Treatment at Green Apple Dental in Surrey (Green Apple Dental. (2024))

4. Advantages of AI in Caries Detection

5. 5.1 Improved Diagnostic Accuracy and Consistency

The problem of artificial intelligence has proven to have a great potential in improving the diagnostic capability of dental caries detection. Deep learning algorithms and especially convolutional neural networks can recognize small radiographic and clinical characteristics that can be missed when performing the traditional examination (12,18). The systems offer stable outputs because they reduce inter- and intra-observer variability as is typical of the traditional diagnostic methods (6,13). Consequently, AI-assisted diagnosis would help clinicians achieve better and more consistent clinical decision-making (20).

5.2 Early Detection and Preventive Care

Among the most important benefits of AI in dentistry, there should be considered the possibility to identify early carious lesions, including non-cavitated enamel demineralization (7,29). The timely diagnosis helps to initiate preventive and minimally invasive treatment measures, which minimizes the effects of the extensive restorative action (49). The AI-based systems have the capability to detect small structural and density alterations in the dental tissues that can be used to intervene in time and provide better oral health outcomes in the long-term (30).

5.3 Time Efficiency and Workflow Optimization

Clinical efficiency can be greatly enhanced with the help of AI technologies since they analyze dental images and deliver quick diagnostic results (53). This saves them on time spent in manual interpretation and enables clinicians to spend more time on patient care and treatment planning (54). AI can facilitate operational procedures, promote efficiency, and minimize delays in diagnosis in high-volume hospitals (37). Moreover, it can be connected to digital dental systems and provides flawless data processing and real-time decision support (55).

5.4 Reduction of Human Error

The possibility of human error during the diagnosis of caries can be due to exhaustion, level of experience, and subjective interpretation of diagnostic images (8). With proper training on quality datasets, AI systems can handle the repetitive tasks associated with diagnostics with a high level of accuracy and will not become tired (31). This decreases the chances of lesions missed or misdiagnosed and leads to a better overall diagnosis reliability (32). Therefore, AI is an effective supplement to the clinical skill and not a substitute increasing the quality of dental service provision (14).

6. Challenges and Limitations

6.1 Data Quality and Dataset Limitations

Caries detection systems based on artificial intelligence are strongly sensitive in relation to the quality, size and diversity of the datasets they are trained on. Several of the current researches depend on quite small or institution-based datasets, which can put a limit on the external validity of the created models (27,28). The imaging methods, resolution, and annotation procedures may cause bias and influence model performance (33). Also, there are no standardized and publicly available datasets on dentistry, which is also a major obstacle on the way to the creation of effective and universal AI systems (23).

6.2 Lack of Standardization and Validation

One of the key problems with AI in the clinical application is the lack of standard procedures to develop, validate, and report the models. The study design, evaluation measures, and validation methodologies differ and complicate the ability to compare the outcomes of studies (41,43). Numerous AI models receive retrospective validation, and fewer are prospectively or real-life clinically validated (30). This poses questions about their predictability and success in the daily practice of dentistry (20). It is necessary to set universal rules and regulations that will allow safe and efficient application of AI technologies in the dental field (14).

6.3 Ethical Concerns and Data Privacy

The application of AI in the healthcare sector presents significant ethical concerns, especially in the context of privacy and data security of patients. AI systems need high amounts of clinical and imaging data, which can contain sensitive patient data (9). The important issue is to ensure that the data protection regulations are followed and that the confidentiality of patients is also maintained (52). Moreover, the problems of data ownership, informed consent, and their possible abuse should be tackled to support the trust in AI-based healthcare solutions (51).

6.4 Interpretability and "Black Box" Issues

Most state-of-the-art AI models, in particular, deep learning algorithms, are so called black box, i.e. the process of their making decisions cannot be easily understood by clinicians (19). Such a deficiency in transparency could decrease the levels of clinician trust and become a barrier to extensive implementation in clinical practice (18). It is important to understand how AI systems come to a particular diagnostic conclusion in order to achieve accountability and clinical decision-making (22). Explainable AI (XAI) methods are created to eliminate this shortcoming by presenting more transparent and understandable results (31).

6.5 Clinical Adoption Barriers

Although AI can be highly effective, there are a number of obstacles that make it difficult to implement into daily dental practice. These are high implementation expenditure, the absence of technical knowledge, and unwillingness to adopt emerging technologies by clinicians (53). Also, AI systems may be complicated to integrate with the current clinical workflows and software platforms (55). The issues of legal responsibility and the accuracy of AI-based diagnosis also add to reluctance to adopt AI (54). To overcome these difficulties, it is necessary to have an interdisciplinary approach, train clinicians, and create effective AI tools that address clinical requirements (37).

7. Future Perspectives and Emerging Trends

7.1 Explainable Artificial Intelligence in Dentistry

Among the directions that are the most likely to make AI progress in the dental field, one can distinguish the work on explainable artificial intelligence (XAI). In contrast to other types of black box models, XAI focuses on offering transparent and interpretable outputs that enable clinicians to comprehend the process of making a diagnosis (19,31). This is more critical in medical care whereby clinical accountability and trust matters a lot. There is an increasing trend of visualization used to point out regions of interest in a dental image, e.g., heat maps and saliency maps, to improve the interpretability and confidence of clinicians (22). It is hoped that the XAI integration will be instrumental in reducing the gap between AI systems and clinical practice (18).

7.2 Integration with Teledentistry and Mobile Applications

Artificial intelligence (AI) and teledentistry application integrations along with mobile health apps are a promising step towards increasing oral health accessibility. It is possible to use AI-driven systems to scan the photographs

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taken with the help of smartphones or portables and conduct remote screening and diagnose dental caries at an early stage (52). The method is also useful in needy and rural communities where dental professionals are inaccessible (3). AI-based Teledentistry can be used to support a timely referral, remote consultation, and continuous patient monitoring, which improves prevention and minimizes the disease burden (50).

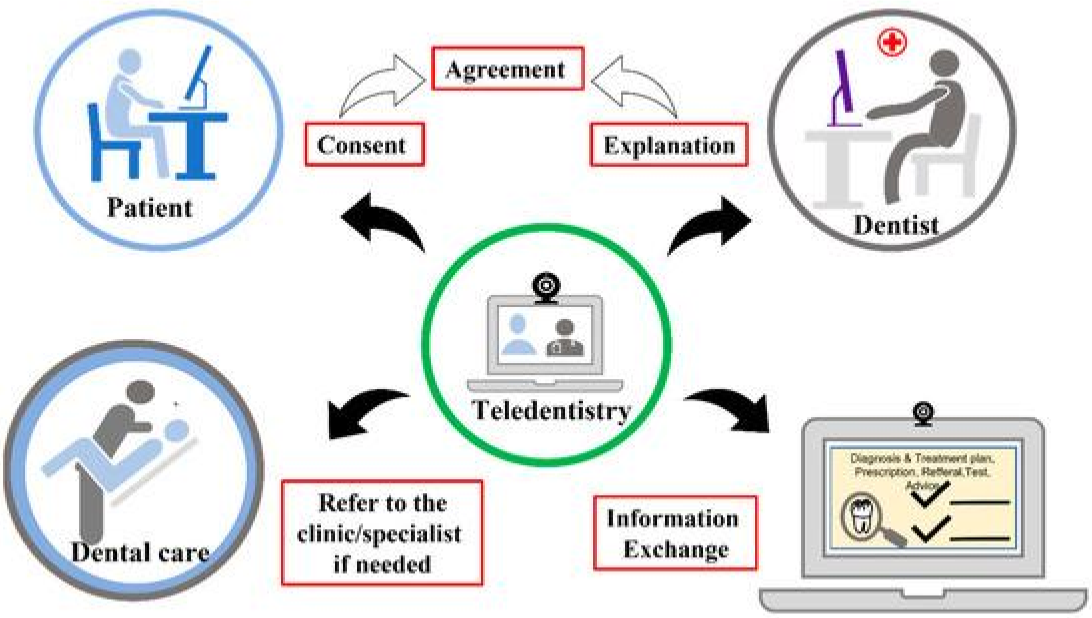

Figure 2. A feasible and practical workflow of an online real-time consultation between patient and dentist.

7.3 Real-Time Chairside AI Tools

The innovation of real-time AI based diagnostic applications to be used in clinics is changing the practice in the field of dentistry. Such systems may be incorporated with the software of dental imaging, and it has been suggested to obtain immediate analysis of radiographs and intraoral images when patients visit the clinic (53). Real-time feedback ensures that clinicians make informed decisions in the real-time basis as applied in diagnosis and treatment planning (54). These tools are efficient as well as they improve communication with patients by visually illustrating the results of the diagnosis (55). Due to improvements in technology, AI applications at the chairside will be more precise, easy to use, and popular (37).

7.4 Personalized and Predictive Dentistry

The transition to personalized and predictive dentistry is also being pushed by AI, which allows predicting risks based on data and tailoring the treatment plan. Artificial intelligence systems have the potential to assess patient-directed variables, such as their clinical history, behavioral patterns, and genetic susceptibilities, which will be used to forecast caries risk and disease progression (51). This enables specific preventive measures and minimally invasive procedures that address the needs of specific patients (49). The combination of AI and electronic health records as well as big data analytics also contributes to the further evolution of precision dentistry, which will eventually lead to better patient outcomes and oral health over time (52).

8. Conclusion

Artificial intelligence has become a ground-breaking instrument in the dental caries detection sphere, bringing substantial advances in the accuracy, effectiveness and consistency of the diagnosis. Deep learning-based systems deployed with AI have also been shown to identify lesions at an early stage and assist doctors in making a clinical decision with a high level of accuracy. Regardless of such improvements, a range of issues, such as data constraints, insufficiency of standardization, ethical issues, and interpretability problems, should be overcome to guarantee effective and safe clinical practices. The challenge of AI in dental practice in the future is the creation of explainable, accessible, and clinically validated systems that can be effortlessly incorporated into the daily practice. There are innovations like real-time chairside solutions, integrations of teledentistry, and customized predictive modeling that will probably improve the position of AI in preventive and precision dentistry even more. Further studies, multidisciplinary cooperation, and the development of regulation tasks will play a key role in achieving the full potential of AI in enhancing the results of oral healthcare.

Reference

1. Schwendicke F, Samek W, Krois J. Artificial intelligence in dentistry: chances and challenges. *J Dent Res*. 2020;99(7):769–74.
2. Khanagar SB, et al. Developments, application, and performance of artificial intelligence in dentistry – A systematic review. *Diagnostics*. 2021;11(3):508.
3. Schwendicke F, et al. Deep learning for caries detection and classification. *J Dent*. 2020;102:103443.
4. Krois J, et al. Deep learning for detection of proximal caries in bitewing radiographs. *J Dent*. 2019;90:103226.
5. Lee JH, et al. Detection and diagnosis of dental caries using deep learning. *Sci Rep*. 2018;8:1231.
6. Cantu AG, et al. Detecting caries lesions using deep learning. *J Dent*. 2020;100:103425.
7. Geetha V, et al. Dental caries diagnosis in digital radiographs using deep learning. *J Clin Med*. 2020;9(8):2441.
8. Hung M, et al. Machine learning applications in dentistry. *J Dent Res*. 2019;98(5):500–9.
9. Moutselos K, et al. Artificial intelligence applications in dentistry: A review. *Diagnostics*. 2022;12(3):667.
10. Pauwels R. Artificial intelligence for dental imaging. *Dentomaxillofac Radiol*. 2021;50(1):20200397.
11. Schwendicke F, Golla T, Krois J. Convolutional neural networks for dental image diagnostics. *J Dent Res*. 2021;100(4):345–52.
12. Samek W, et al. Explainable AI: interpreting deep neural networks. *Proc IEEE*. 2021;109(3):247–78.
13. Litjens G, et al. A survey on deep learning in medical imaging. *Med Image Anal*. 2017;42:60–88.

14. Rajpurkar P, et al. AI in medical imaging: recent advances. *Lancet Digit Health*. 2022;4:e35–45.
15. Topol EJ. High-performance medicine: convergence of AI and human intelligence. *Nat Med*. 2019;25:44–56.
16. Abesi F, et al. Diagnostic accuracy of bitewing radiographs. *J Dent*. 2020;95:103304.
17. Kühnisch J, et al. Diagnostic performance of visual vs radiographic detection. *Clin Oral Investig*. 2020;24:123–32.
18. Ekstrand KR, Ricketts DNJ, Kidd EAM. Reproducibility and accuracy of three methods for assessment of demineralization depth of occlusal caries lesions. *Caries Res*. 1997;31(3):224–31.
19. Wenzel A. Bitewing and digital bitewing radiography for detection of caries lesions. *J Dent*. 2004;32(7):543–52.
20. European Commission. Radiation Protection No. 172: Cone beam CT for dental and maxillofacial radiology. Luxembourg: European Commission; 2012.
21. 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;9:3840.
22. Zhang Y, Chu C, Zhou X, Li C. Automatic detection of dental caries based on deep learning. *IEEE Access*. 2020;8:172842–52.
23. Singh P, Sehgal P, Kaur H. A review of image processing techniques for dental caries detection. *Comput Biol Med*. 2020;123:103912.
24. Kumar S, Kaur H, Kaur P. Support vector machine-based classification for dental disease detection. *J Med Syst*. 2020;44:123.
25. Patel J, Shah M, Patel N. Machine learning approaches in dental diagnostics: a review. *Diagnostics*. 2021;11(6):1005.
26. Ronneberger O, Fischer P, Brox T. U-Net: Convolutional networks for biomedical image segmentation. In: *MICCAI*. 2015. p. 234–41.

27. Schwendicke F, Krois J, Gomez J. Artificial intelligence in dentistry: a review. *J Dent Res*. 2020;99(7):769–74.
28. Bianchi J, de Oliveira AEF, Rodrigues JA. Artificial intelligence and machine learning in dentistry: current applications and future perspectives. *J Dent*. 2022;114:103824.
29. Davenport T, Kalakota R. The potential for artificial intelligence in healthcare. *Future Healthc J*. 2019;6(2):94–8.
30. Park WJ, Park JB. History and application of artificial neural networks in dentistry. *Eur J Dent*. 2018;12(4):594–601.
31. Powers DMW. Evaluation: from precision, recall and F-measure to ROC. *J Mach Learn Technol*. 2011.
32. Peres MA, Macpherson LMD, Weyant RJ, Daly B, Venturelli R, Mathur MR, et al. Oral diseases: a global public health challenge. *Lancet*. 2019;394(10194):249–60.
33. Petersen PE. Global oral health status report. *Community Dent Oral Epidemiol*. 2020;48(1):1–8.
34. Frencken JE, Peters MC, Manton DJ, Leal SC, Gordan VV, Eden E. Minimal intervention dentistry. *Int Dent J*. 2020;70(4):223–31.
35. Khanagar SB, Al-Ehaideb A, Vishwanathaiah S, et al. Scope and performance of AI in dentistry: systematic review. *Diagnostics*. 2021;11(3):508.
36. Rajpurkar P, Chen E, Banerjee O, Topol EJ. AI in medical imaging: the next frontier. *Lancet Digit Health*. 2022;4(2):e35–e36.
37. Krois J, Ekert T, Meinhold L, et al. Deep learning for detection of proximal caries. *J Dent*. 2019;90:103226.
38. Lee JH, Kim DH, Jeong SN, Choi SH. Detection of dental caries using deep learning. *Sci Rep*. 2018;8:1231.
39. Geetha V, Aprameya KS, Hinduja DM. Dental caries diagnosis using deep learning. *J Clin Med*. 2020;9(8):2441.

40. Cantu AG, Gehrung S, Krois J, Chaurasia A, Rossi JG, Gaudin R, et al. Detecting caries lesions using deep learning. *J Dent*. 2020;100:103425.
41. Schwendicke F, Krois J. Artificial intelligence in dentistry: current applications and future perspectives. *Br Dent J*. 2022;233(6):469–74.
42. Tuzoff DV, Tuzova LN, Bornstein MM, Krasnov AS, Kharchenko MA, Nikolenko SI, et al. Tooth detection and numbering in panoramic radiographs using deep learning. *Dentomaxillofac Radiol*. 2019;48(4):20180051.
43. Miki Y, Muramatsu C, Hayashi T, Zhou X, Hara T, Katsumata A, et al. Classification of teeth in cone-beam CT using deep convolutional neural networks. *Comput Biol Med*. 2017;80:24–9.
44. Casalegno F, Newton T, Daher R, Abdelaziz M, Lodi-Rizzini A, Schürmann F, et al. Caries detection with near-infrared transillumination using deep learning. *J Dent Res*. 2019;98(11):1227–33.
45. Srivastava MM, Kumar P, Pradhan L, Varadarajan S. Detection of dental anomalies in radiographs using deep learning. *IEEE J Biomed Health Inform*. 2017;21(6):1604–12.
46. Chen H, Zhang K, Lyu P, Li H, Zhang L, Wu J, et al. Automatic tooth detection and numbering using deep learning. *Sci Rep*. 2019;9:3840.
47. Lee JH, Kim DH, Jeong SN, Choi SH. Deep learning for detection of dental caries. *Sci Rep*. 2018;8:1231.
48. Krois J, Ekert T, Meinhold L, et al. Deep learning improves caries detection accuracy. *J Dent*. 2019;90:103226.
49. Schwendicke F, Elhennawy K, Paris S, Friebertshäuser P, Krois J. Deep learning for caries detection: systematic review. *J Dent*. 2020;99:103310.
50. Hung M, Voss MW, Rosales MN, et al. Application of machine learning in predicting dental caries. *J Dent Res*. 2020;99(6):634–40.
51. Fontana M, Zero DT. Assessing patients' caries risk. *J Am Dent Assoc*. 2006;137(9):1231–9.

52. Estai M, Kanagasingam Y, Xiao D, et al. Teledentistry as a novel pathway to improve oral health. *Int J Environ Res Public Health*. 2018;15(6):1306.
53. Tonmukayakul U, Arrow P. Cost-effectiveness of teledentistry. *J Dent*. 2017;63:53–60.
54. Daniel SJ, Kumar S. Teledentistry: a key component in access to care. *J Evid Based Dent Pract*. 2014;14:201–8.
55. Topol EJ. Preparing the healthcare workforce for AI integration. *Nat Med*. 2019;25:44–56.
56. Jiang F, Jiang Y, Zhi H, Dong Y, Li H, Ma S, et al. Artificial intelligence in healthcare: past, present and future. *Stroke Vasc Neurol*. 2017;2(4):230–43.