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Artificial Intelligence in Dentistry: Current Applications and Future Perspectives

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ABSTRACT

Artificial intelligence (AI) is increasingly transforming modern dentistry by supporting diagnosis, treatment planning, image interpretation, disease prediction, and clinical decision-making. The rapid development of digital radiography, cone-beam computed tomography, intraoral scanners, facial imaging, and electronic health records has generated large volumes of data that can be analyzed using machine-learning and deep-learning algorithms. AI has demonstrated applications in dental and maxillofacial radiology, restorative dentistry, endodontics, periodontology, orthodontics, implantology, prosthodontics, oral medicine, and dental education. Although AI offers advantages such as improved efficiency, consistency, and diagnostic support, concerns regarding data bias, privacy, transparency, external validation, and ethical responsibility remain. Therefore, AI should be considered an adjunct to clinical expertise rather than a replacement for the dentist. [1-3]

Keywords: Artificial intelligence; dentistry; machine learning; deep learning; digital dentistry; diagnosis.

INTRODUCTION

Artificial intelligence refers to computer-based technologies capable of performing tasks that traditionally require human intelligence, including learning, pattern recognition, problem-solving, prediction, and decision-making. AI has become increasingly important in healthcare because of its ability to process large and complex datasets rapidly. Machine learning enables computer systems to learn patterns from data, whereas deep learning uses multilayered neural networks to identify complex relationships, particularly in images and other high-dimensional datasets. [1-3]

Dentistry is particularly suitable for the application of AI because contemporary dental practice is increasingly digital. Radiographs, CBCT scans, intraoral photographs, digital dental models, facial images, periodontal charts, and electronic patient records provide a large amount of information that can potentially be analyzed by AI algorithms. These technologies may assist clinicians by automating repetitive tasks, identifying abnormalities, predicting outcomes, and supporting clinical decision-making. [2-4]

The development of AI in dentistry has progressed from simple computer-assisted systems to sophisticated deep-learning models capable of image classification, object detection, segmentation, landmark identification, and predictive analysis. Among different dental specialties, dental and maxillofacial radiology has emerged as one of the most extensively investigated

fields, followed by orthodontics, endodontics, periodontology, and restorative dentistry. [1,3,4]

Artificial Intelligence in Dental and Maxillofacial Radiology

Dental and maxillofacial radiology represents one of the most important areas for AI application. Interpretation of radiographic images requires the identification of subtle anatomical and pathological features, making this specialty particularly suitable for deep-learning-based image analysis. AI algorithms have been developed for tooth detection and numbering, caries identification, detection of periapical lesions, periodontal bone-loss assessment, cephalometric landmark identification, and classification of radiographic abnormalities. [1,4,5]

Convolutional neural networks are particularly useful for analyzing dental images because they can automatically recognize relevant image features. Unlike conventional image-analysis methods, deep-learning systems can learn complex patterns directly from large datasets. This has enabled the development of algorithms capable of analyzing panoramic, periapical, bitewing, and CBCT images with increasing accuracy. [3,4]

AI-assisted radiographic interpretation may improve efficiency and reduce observer variation, especially during repetitive diagnostic procedures. However, the performance of an algorithm may vary when it is applied to images obtained using different radiographic machines, exposure parameters, or patient populations. Therefore, a system demonstrating high accuracy in one dataset may not necessarily perform equally well in routine clinical practice. [1,2]

Artificial Intelligence in Cariology and Restorative Dentistry

Dental caries remains one of the most common oral diseases worldwide, and early detection is important for effective preventive and minimally invasive management. AI-based systems have been developed to analyze radiographic images and identify carious lesions, particularly proximal caries. Deep-learning algorithms may assist clinicians by highlighting suspicious areas and reducing the possibility of overlooked lesions. [5,6]

AI may also contribute to restorative dentistry by assisting in the detection of recurrent caries, defective restorations, and restoration margins. In addition, AI-supported digital workflows may help in tooth segmentation, restoration design, and evaluation of dental morphology. Such technologies may improve the efficiency of CAD/CAM-based restorative procedures. [2,3]

Despite these advantages, AI-based caries detection should not be considered an independent indication for restorative treatment. Clinical decisions must also consider lesion activity, cavitation, caries-risk status, preventive possibilities, and patient-specific factors. Thus, AI should assist the clinician in diagnosis rather than determine treatment independently. [2,5]

Artificial Intelligence in Endodontics

In endodontics, AI has primarily been investigated for radiographic diagnosis and interpretation. Deep-learning systems have demonstrated the ability to identify periapical radiolucencies and other pathological changes on dental radiographs. Such systems may provide additional support during the interpretation of images in which lesions are subtle or difficult to identify. [7]

AI may also be useful for identifying root morphology, detecting additional root canals, evaluating root resorption, and analyzing complex anatomical structures using CBCT images. These applications could improve treatment planning and help clinicians recognize anatomical variations that may influence the outcome of endodontic treatment. [4,7]

However, radiographic findings alone cannot establish a complete endodontic diagnosis. Clinical symptoms, pulp vitality tests, periodontal examination, and the patient's

history must also be considered. Therefore, AI-generated findings should always be interpreted within the complete clinical context. [2,7]

Artificial Intelligence in Periodontology

AI has demonstrated promising applications in periodontal diagnosis, particularly in the automated assessment of radiographic bone loss. Deep-learning algorithms can analyze dental radiographs and estimate the extent of alveolar bone loss, potentially supporting periodontal disease classification and improving the consistency of radiographic assessment. [8,9]

AI may also contribute to the prediction of periodontal disease progression by integrating radiographic findings with clinical parameters and patient-related risk factors. In the future, multimodal AI systems may combine probing depth, clinical attachment level, bleeding on probing, plaque scores, smoking history, and radiographic data to provide more individualized risk assessment. [2,9]

Nevertheless, periodontal diagnosis cannot be based on radiographic findings alone. The clinical examination remains essential, and AI should be considered a supplementary tool for evaluating periodontal destruction and monitoring disease progression. [8,9]

Artificial Intelligence in Orthodontics

Orthodontics is highly compatible with AI because of its extensive use of digital records, cephalometric radiographs, photographs, intraoral scans, and three-dimensional imaging. AI has been investigated for automated cephalometric landmark identification, skeletal classification, dental age estimation, growth assessment, treatment planning, and prediction of orthodontic outcomes. [10-12]

Automated cephalometric analysis is one of the most widely studied applications. AI-based systems can identify cephalometric landmarks and perform measurements within a short period, potentially reducing the time required for manual tracing. Such systems may also improve the reproducibility of routine analyses, although landmark accuracy can vary depending on the anatomical structure and image quality. [10,11]

AI may also support orthodontic diagnosis by classifying skeletal patterns, evaluating craniofacial morphology, and assisting with treatment planning. With the increasing use of clear aligners and digital treatment platforms, AI may further contribute to automated tooth segmentation, treatment simulation, aligner monitoring, and identification of deviations from planned tooth movement. [12,13]

Despite its potential, AI cannot independently determine the ideal orthodontic treatment plan. Extraction decisions, biomechanics, facial esthetics, periodontal limitations, growth potential, patient compliance, and individual treatment objectives require professional clinical judgment. Therefore, AI should function as a decision-support system while the orthodontist remains responsible for the final treatment plan. [2,12]

Artificial Intelligence in Implant Dentistry and Prosthodontics

AI has potential applications throughout the implant treatment workflow. Preoperative applications include CBCT analysis, anatomical structure identification, bone assessment, implant-site evaluation, and digital treatment planning. Automated identification of structures such as the mandibular canal and maxillary sinus may improve the efficiency and safety of implant planning. [3,4]

In prosthodontics, AI can contribute to digital workflows by assisting in tooth segmentation, crown design, smile analysis, and selection of tooth morphology. Integration of AI with CAD/CAM technology may reduce repetitive design procedures and allow more individualized prosthetic planning. [2,3]

Future AI systems may integrate anatomical, functional, occlusal, and patient-specific information to predict treatment outcomes and prosthetic longevity. However,

biological factors, material properties, occlusion, and patient maintenance continue to play a major role in determining long-term success. [2,18]

Artificial Intelligence in Oral Medicine and Oral Pathology

AI has been investigated for the identification and classification of oral lesions, including potentially malignant disorders and oral cancer. Deep-learning algorithms can analyze clinical photographs, radiographic images, and histopathological slides to identify patterns associated with pathological changes. Such technologies may eventually assist in screening and early detection. [3,4]

AI-supported screening may be particularly valuable in regions where access to specialists is limited. However, the consequences of false-positive and false-negative results can be significant. Therefore, AI-based systems should not replace clinical examination, biopsy, histopathological assessment, or specialist consultation when required. [2,3]

Generative Artificial Intelligence and Dental Education

Generative AI and large language models have introduced new possibilities for dental education, research, communication, and documentation. These technologies can assist in summarizing scientific information, generating educational content, preparing patient instructions, and organizing clinical documentation. [16,17]

In dental education, AI-based systems may provide adaptive learning experiences, generate practice questions, simulate clinical scenarios, and provide feedback. Such applications may help students understand complex concepts and access educational material more efficiently. [3,17]

However, generative AI can produce inaccurate information and fabricated references. Students, clinicians, and researchers should therefore critically evaluate all AI-generated content and verify scientific information using reliable sources. AI should support learning and critical thinking rather than replace independent understanding and academic responsibility. [16,17]

Advantages of Artificial Intelligence in Dentistry

One of the major advantages of AI is its ability to process large volumes of data rapidly. Routine tasks such as tooth numbering, image segmentation, cephalometric landmark identification, and measurement of periodontal bone loss may be automated, potentially reducing the workload associated with repetitive procedures. [1-4]

AI may also improve consistency by reducing variations between observers. In diagnostic imaging, different clinicians may interpret the same radiograph differently depending on their experience and training. A properly validated AI system may provide a standardized secondary assessment and help clinicians identify suspicious findings. [1,18]

Another important potential advantage is personalized dentistry. Predictive AI models may eventually help estimate disease risk, treatment duration, probability of complications, and expected treatment outcomes. Such information could support individualized prevention and treatment planning. [2,3]

Limitations and Challenges

Despite promising results, several challenges limit the widespread clinical implementation of AI in dentistry. A major concern is the quality and diversity of the data used to train AI algorithms. Systems developed using limited or nonrepresentative datasets may perform poorly when applied to different populations or clinical settings. [2,19]

Another important limitation is the lack of adequate external validation. Many AI studies are retrospective and conducted using data from a single institution. Before widespread clinical adoption, algorithms should be tested using independent datasets

and evaluated in real clinical environments. [18,19]

The lack of transparency of some deep-learning algorithms also remains a challenge. Complex models may provide an output without clearly explaining how the decision was reached. This "black-box" nature may reduce clinician confidence and create difficulties when an algorithmic recommendation conflicts with clinical findings. [2,18]

Ethical and Legal Considerations

AI in dentistry raises important ethical questions related to patient privacy, data ownership, informed consent, bias, and professional responsibility. Dental images and clinical records contain sensitive patient information, and appropriate safeguards are necessary to ensure secure data collection, storage, and processing. [2,19]

Algorithmic bias is another important concern. If the training data do not adequately represent diverse patient populations, the performance of the system may differ between groups. Developers and clinicians should therefore evaluate AI systems for fairness and generalizability before clinical implementation. [18,19]

The dentist must remain responsible for the final clinical decision. AI may provide valuable recommendations, but it cannot assume professional accountability for patient care. A human-in-the-loop approach, in which the clinician evaluates and interprets the AI output, is therefore considered the most appropriate model for the responsible use of AI in dentistry. [2]

Future Perspectives

The future development of AI in dentistry is likely to focus on multimodal systems that integrate different sources of patient information. Radiographs, CBCT scans, intraoral scans, facial photographs, clinical records, and treatment history could potentially be analyzed together to provide a more comprehensive assessment of oral health. [3,19]

AI may also play an important role in precision dentistry. Predictive algorithms could help identify patients at increased risk of dental disease, estimate individual treatment responses, and predict complications before they occur. This may enable more personalized preventive and therapeutic strategies. [2,3]

Generative AI, robotics, computer vision, and advanced digital workflows may further expand the role of AI in dentistry. However, technological progress must be accompanied by strong clinical validation, appropriate regulation, transparency, and ethical governance. The successful implementation of AI should ultimately be evaluated not only by algorithmic accuracy but also by its ability to improve clinical efficiency, patient outcomes, and the quality of oral healthcare. [17,19,]

CONCLUSION

Artificial intelligence is becoming an increasingly important component of modern dentistry. Its applications extend from radiographic interpretation and disease detection to orthodontic analysis, treatment planning, implantology, prosthodontics, education, and predictive healthcare. Among these applications, AI-assisted image analysis currently represents one of the most developed areas. [1-4]

Although AI has the potential to improve efficiency, consistency, and diagnostic support, important limitations related to bias, data quality, privacy, transparency, and clinical validation remain. High algorithmic accuracy alone should not be considered sufficient evidence for clinical adoption. AI systems must demonstrate that they can safely and meaningfully improve patient care. [2,18,19]

The future of dentistry is therefore unlikely to involve the replacement of dentists by artificial intelligence. Instead, AI is expected to become an increasingly powerful tool that complements clinical expertise. The optimal approach will combine the computational capabilities of AI with the experience, judgment, ethical responsibility, and human

interaction provided by the dental professional. [2,16,20]

Declaration by Authors

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