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Review Article

Applications of Artificial Intelligence in Dentistry: A Narrative Review

Arpit Sikri[1*], Jyotsana Sikri[2], Vritti Piplani[3], Yamika Thakur[3]

[1]Associate Professor & Post Graduate Teacher, Department of Prosthodontics and Crown and Bridge, Bhojia Dental College & Hospital, Baddi, Himachal Pradesh, India
[2]Associate Professor & Post Graduate Teacher, Department of Conservative Dentistry & Endodontics, Bhojia Dental College & Hospital, Budh (Baddi), Teh. Baddi, Distt. Solan, Himachal Pradesh, India
[3]BDS Intern Bhojia Dental College & Hospital, Budh (Baddi), Teh. Baddi, Distt. Solan, Himachal Pradesh, India

***Corresponding Author:** Arpit Sikri
Associate Professor & Post Graduate Teacher, Department of Prosthodontics and Crown and Bridge, Bhojia Dental College & Hospital, Baddi, Himachal Pradesh, India

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Abstract: Artificial intelligence, rooted in the information technology sector, stands as a transformative force driven by sophisticated software mechanisms that confer numerous benefits across a wide array of societal domains. Among these, its integration into the healthcare sector, including dentistry, has proven to be a source of considerable success. The impact is particularly noteworthy in the realm of preventive healthcare, where AI demonstrates substantial potential for advancing early diagnosis, ultimately resulting in elevated treatment efficacy. The exploration of diverse use cases reveals a promising landscape where AI not only facilitates precision in diagnostics but also plays a pivotal role in optimizing treatment outcomes. Through its analytical capabilities and pattern recognition, AI contributes to a more nuanced and accurate early detection of dental issues, thereby empowering dental professionals to intervene at the earliest stages. The implications extend beyond diagnostic accuracy, encompassing tangible improvements in the overall patient experience. By leveraging AI, treatment durations can be streamlined, leading to more efficient and effective interventions. This not only translates to enhanced patient comfort but also contributes to the professional satisfaction of dental practitioners who can deliver high-quality care with greater precision. Furthermore, the synthesis of AI into dental practices introduces a dynamic paradigm shift, fostering a synergy between technology and human expertise. As algorithms evolve and learn from vast datasets, they augment the diagnostic acumen of dental professionals, providing valuable insights that may have been challenging to discern through traditional means alone. This narrative review explores the diverse applications of artificial intelligence in dentistry, emphasizing its transformative potential. From early diagnosis to treatment optimization, the integration of AI not only enhances clinical outcomes but also fosters a more patient-centric and efficient approach to dental care. The evolving collaboration between AI and dental practitioners is set to redefine oral healthcare, paving the way for a future where precision and efficiency converge to elevate the standards of dental medicine.

Keywords: Artificial intelligence, Deep learning, Dental specialties, Dentistry, Machine learning, Neural networks.

INTRODUCTION

The advancement of technology has introduced diverse applications in the realm of artificial intelligence (AI) and its components [1]. Emerging from the field of computer science, AI involves technology with software-driven mechanisms, capable of providing benefits through its utilization. It encompasses systems that emulate human processes [2].

The term AI is primarily associated with robotics, denoting the use of technology to create software that mimics human intelligence, undertaking specific tasks [3]. The inception of artificial intelligence dates back to 1956 with Dartmouth, marking a significant milestone in research, including neural networks and other computer theories [4].

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However, AI faced initial challenges, such as high expectations and limitations like data accessibility. Today, AI broadly refers to any technology that can simulate human cognitive abilities [5].

In a broader context, the objective is to perform tasks traditionally requiring human intervention, employing machines to emulate human actions. The overarching purpose of utilizing this technological resource is to expedite work across various sectors, aiming to reduce task completion time [6].

Artificial intelligence is characterized by the ability of technology to exhibit a form of its own intelligence, with the goal of developing machines capable of learning from data to solve problems. Presently, several resources in AI include Machine Learning, Deep Learning, and Natural Language Processing [7]. Machine learning employs algorithms to predict outcomes based on datasets, facilitating machine learning from data to solve problems without human intervention [8]. Neural networks, algorithms calculating signals through artificial neurons, seek to emulate the human brain [9].

Deep learning, a subset of machine learning, utilizes multiple neural layers between input and output layers to automatically identify patterns [10]. Commonly known as convolutional neural networks, it is widely applied in processing large and complex images, particularly in Dentistry [11]. Rapid technological advances, especially in deep learning, enable AI applications across all sectors of society [12]. AI, represented by deep learning, can enhance patient care by aiding in diagnosis and reducing errors in clinical practice [13]. The application of AI, particularly in dentistry, has proven satisfactory in the healthcare sector [14].

In dentistry, AI can improve preventive approaches, enabling early diagnosis for better treatment outcomes. Integration of software with AI facilitates quick analysis, storage, and comparison of data [15]. The technology aims to minimize errors in dental treatments, streamline work processes, and support clinical decision-making, ultimately enhancing the role of dental surgeons [16]. The present narrative review article's goal is to explore various AI applications in dental medicine and different specialties, while also examining how AI approaches human expertise levels in diverse dental contexts.

DISCUSSION

In the past year, there has been a remarkable surge in the publication of articles addressing the utilization of artificial intelligence across diverse dental specialties [17]. This underscores the widespread adoption of this technology, particularly in the identification of lesions through various imaging methods, predominantly X-rays, which are primarily employed for evaluating the conditions of hard tissues [18]. Over time, periapical, panoramic, and cephalometric X-rays have become integral in this regard. In 2009, Flores *et al*., introduced an AI model utilizing CBCT images from patients to distinguish periapical cysts from granulomas [19]. Subsequently, numerous studies have endeavored to create AI models based on CBCT images to address a range of issues [20]. The majority of these studies concentrate on all the nine key applications spanning various dental specialties, including periodontics, oral implantology, forensic dentistry, oral medicine and pathology, orthodontics, maxillofacial surgery, diagnosis, cariology, and endodontics, prosthodontics, crown & bridge, and pedodontics and preventive dentistry.

Prosthodontics

Desktop design and CAD/CAM fabrication have become standard in healthcare and labs. Creating removable and fixed dental prostheses for edentulous patients is challenging due to the high aesthetic and functional criteria that must be satisfied [21]. The machine learning capabilities of CAD/CAM software can realign teeth to restore inter-maxillary connections [22]. Artificial intelligence (AI) may assist in precise color matching, especially in difficult aesthetic situations involving a single central incisor or several anterior teeth [23]. In implant prosthodontics, implant locations can be identified using intraoral detectors, and this information can be inputted into the CAD program in real-time [24]. Artificial intelligence (AI) has the potential to enhance dental implant design and fabrication [25].

Periodontics

Periodontal disease is a multifaceted inflammatory condition influenced by multiple contributing factors that act simultaneously and interactively. It stands as one of the most prevalent oral diseases affecting humanity [26]. Lee *et al*., have extensively documented that the ongoing progression of this disease can ultimately result in the loss of teeth in adults [27]. Numerous studies have explored the application of AI technology in diagnosing and predicting periodontal diseases [28].

Lee *et al*., introduced the use of a CAD system based on a deep convolutional neural network (CNN) algorithm for diagnosing and predicting compromised teeth with periodontal health issues. The CNN algorithm demonstrated an accuracy range of 76.7–81.0% for PCT diagnosis and 73.4–82.8% for predicting the need for extraction [29]. Notably, variations in accuracy were observed between different types of teeth, with premolars exhibiting higher accuracy in PCT diagnosis (82.8%) compared to molars (73.4%) [30]. This difference could be attributed to the simpler anatomy of

premolars, typically having a single root, compared to molars, which have 2 or 3 roots, presenting a more complex structure for the CNN to interpret.

Yauney *et al*., utilized an AI-based system employing CNNs to correlate poor periodontal health with systemic health outcomes, suggesting that AI can automate diagnoses and serve as a screening tool for other diseases [31]. Papantanopoulos and colleagues employed an artificial neural network (ANN) to distinguish between aggressive and chronic periodontitis based on immunologic parameters. The ANN achieved an accuracy of 90–98% in classifying patients [32]. Wang *et al*., developed a Digital Convolution Neural Network-based system for detecting periodontitis, demonstrating the potential of deep learning analysis using radiographs in diagnosing and planning treatment for periodontal diseases [33].

In addition to enhancing the comprehension of periodontitis, AI technology acts as a bridge, integrating conventional indicators and immunologic and microbiological parameters into periodontal diagnosis [34]. AI programs, particularly those utilizing panoramic X-rays, have been deployed to aid in diagnosing and treating periodontitis [35]. Various AI approaches, such as the Hybrid Framework, R-CNN, CNN self-trained network, and support vector machine, have exhibited high diagnostic accuracy, significantly reducing the time required for periodontal examination [36].

Oral Implantology

Artificial Intelligence (AI) has proven to be highly effective in accurately identifying dental implants [37]. Different AI models, including deep Convolutional Neural Networks (CNN) and YOLOv-3, have been utilized to evaluate the existence and placement of dental implants [38]. Additionally, AI models have been developed to detect peri-implantitis and identify fractures in dental implants [39]. The applications of AI extend to predicting the prognosis of dental implants based on their mesiodistal position, analyzing crown adaptation on implants, and assessing the impact of medications on osseointegration [40]. This highlights the diverse and valuable roles that AI plays in enhancing the precision and comprehensive understanding of various aspects related to dental implants.

Forensic Dentistry

Artificial Intelligence (AI) has been utilized to accelerate the identification process of individuals through dental records, significantly reducing recognition time [41]. Models have been created to estimate the age of individuals based on dental records, and AI has been employed to assess the developmental stage of lower third molars in panoramic X-rays [42]. Furthermore, AI models have been developed to predict chronological age and determine gender using panoramic radiographs [43]. AI-based methods have also been applied to identify sexual dimorphism in canines, showcasing the versatility of AI in various aspects of dental forensics and record analysis [44].

Oral Medicine, Oral Radiology, and Oral Pathology

AI has been instrumental in diagnosing dental cystic lesions through analyses of panoramic and tomographic images [45]. Various algorithms have been employed to predict tumor margin positivity, oral cancer survival, and oral cancer prognosis [46].

In the realm of oral pathology, various AI techniques have been applied. These include Artificial Neural Networks (ANN), Clinical Decision Support System (CDSS), Principal Component Analysis (PCA), Data Mining Techniques, Fuzzy Logic, Belief Merging, Genetic Algorithms (GA), Probabilistic and General Regression Neural Network, Dynamic Bayesian Networks, Atlas-Based Techniques, Deep Learning (DL), and Machine Learning (ML) [47].

In the field of oral radiology, AI applications span across diverse areas, addressing the interpretation of radiographic lesions, automated analysis of dental radiographs, and caries detection [48]. Specific applications within this domain include diagnosing vertical root fractures on CBCT images, staging tooth development, computer-based digital subtraction imaging, 3-dimensional orthodontics visualization, bone density evaluation for predicting osteoporosis, automatic segmentation of the mandibular canal, forensic dental imaging for personal identification, and dental biometrics [49].

Panoramic radiographs serve multiple purposes, including the identification of specific anatomical structures (e.g., teeth, condyle), detection of pathological conditions (e.g., caries, periapical lesions, bone loss), segmentation of specific items, classification of items, and forensic purposes. Deep learning, particularly in diagnostic procedures for tooth analysis, has played a significant role, with automated models being developed to identify, segment, and distinguish teeth based on dentition, quadrant, and category [50]. Despite challenges with low-quality images, recent models have shown improved accuracy in teeth identification and classification, offering promising results for supporting orthodontic clinical practice [51].

Orthodontics & Dentofacial Orthopaedics

An effective AI-based tool for orthodontics should not only provide automated cephalometric analysis but also offer the orthodontist the capability to easily correct predicted landmark identification [52, 53]. Web-based applications for automated cephalometric analysis have now evolved to allow users to perform automatic cephalometric analysis and check the locations of points directly on the webpage [54]. Another crucial feature of robust software is the ability to deliver quick and time-efficient results for automatic cephalometric analysis. For instance, the Planmeca Romexis Cephalometric Analysis Software enables users to obtain a rapid automatic cephalometric tracing in seconds. However, it requires a specific input—the lateral radiograph must be taken with the Planmeca cephalometric imaging unit to ensure proper calibration and orientation [55].

AI has played a significant role in various aspects of orthodontics, including assessing the impact of orthodontic treatment on facial attractiveness and age appearance, predicting the location and angulation of third molars in panoramic radiographs, analyzing cervical vertebrae, segmenting multiclass tomography, predicting tooth extractions, assessing craniofacial differences, automating cephalometric analysis, and monitoring orthodontic treatment [56].

In the realm of digital dental methods, dental models have undergone a technological shift from traditional plaster casts to digitally scanned casts and, more recently, intraoral scans. With these changes, novel AI tools have targeted the analysis of digital dental models (DDMs). New methods, such as segmentation of DDMs, landmark identification, and registration of DDMs, have been proposed to enhance orthodontic diagnosis, planning, and research [57]. This demonstrates the evolving role of AI in improving the precision and efficiency of orthodontic processes and analyses.

Pedodontics & Preventive Dentistry

Assessing children's oral health has often been overlooked compared to other aspects of overall health, particularly in underdeveloped and developing countries. The World Health Organization (WHO) has addressed this concern by developing an oral health questionnaire for both adults and children [58]. To enhance oral health assessment in children, a research team has leveraged machine learning to create toolkits capable of predicting the Children's Oral Health Status Index (COHSI) and Referral for Treatment Needs (RFTN) [59].

Mesiodens and Supernumerary Tooth Identification: Artificial intelligence has proven valuable in diagnosing mesiodens through the use of single deep learning models. The screening performance of young and inexperienced dental personnel often results in missing the presence of supernumerary teeth on panoramic radiographs. CNN-based deep learning can provide substantial support in screening for supernumerary teeth, addressing the limitations posed by the screening performance of less experienced dental professionals [60].

Early Childhood Caries: Research has identified genes and gene polymorphisms associated with dental lesions, but there is a lack of genetic factors in many studies focused on dental caries [61]. Using single nucleotide polymorphisms (SNPs) to predict the risk of dental caries through artificial neural networks could be a valuable tool for clinicians and parents [62]. This approach enables the implementation of preventive strategies during early childhood, improving eating habits, and enhancing overall quality of life for children.

Fissure Sealant Categorization: CNN, a crucial deep learning algorithm, has been employed to assist dental practitioners in categorizing fissure sealants. These sealants, being white in color, are easily identifiable. A research team developed a deep learning-based CNN to identify sealants from machine-readable intraoral photographs [63]. Although this AI-based algorithm demonstrated high diagnostic accuracy, it requires further dental research, repeated training for accurate detection, and comprehensive categorization of diseases and restoration procedures before clinical application.

Chronological Age Assessment in Kids and Adolescents Using Neural Modeling: Dental age assessment, typically analyzed through clinical or pantomographic methods, poses challenges in terms of accuracy. The clinical method, while quick, often produces inaccurate results [64]. Neural modeling, utilizing artificial intelligence, could offer a more accurate and reliable means of assessing chronological age in children and adolescents, providing valuable insights for dental professionals.

Oral and Maxillofacial Surgery

AI is poised to revolutionize the field of Oral and Maxillofacial Surgery (OMFS) by introducing advanced tools and techniques that significantly enhance the accuracy, efficiency, and outcomes of surgical procedures for the reconstruction and rehabilitation of maxillofacial defects. Key applications of AI in OMFS include:

1. **Computer-Aided Design and Computer-Aided Manufacturing (CAD/CAM) [**65].

CAD/CAM employs digital imaging, three-dimensional (3D) photography, intraoral scans, and 3D printing to design and fabricate custom implants, prostheses, guides, and plates tailored for reconstructing maxillofacial defects. This

technology has the potential to reduce costs, streamline the reconstruction process, and improve the fit, function, and aesthetics of the devices.

2. Machine Learning (ML) and Deep Learning (DL)

ML and DL algorithms are utilized to analyze complex datasets and patterns, enabling more accurate decision-making in various aspects of OMFS [66]. AI models, based on ML and DL, have demonstrated high performance in applications such as decision-making for tooth extractions and the localization of anatomical structures, such as the inferior alveolar nerve [67].

3. Artificial Neural Networks (ANNs)

ANNs are employed to model complex relationships and processes, aiding in decision-making and analysis in OMFS [68]. In particular, AI has been applied for decision-making in tooth extractions based on panoramic and cone-beam computed tomography (CBCT) images, showcasing its capability to contribute to treatment planning [69].

4. Bioprinting and Tissue Engineering [70].

AI facilitates the use of bioprinters to fabricate scaffolds that can receive grafts and tissue engineering products, offering innovative solutions for the reconstruction of maxillofacial defects. This approach holds promise for creating customized and biocompatible structures to support the regeneration of tissues in the oral and maxillofacial region.

By integrating AI into OMFS, these applications collectively contribute to advancements in precision, cost-effectiveness, and overall quality of care for patients undergoing maxillofacial reconstruction. The technology not only enhances the surgical process but also has the potential to improve postoperative outcomes and patient satisfaction.

Diagnosis, Cariology, and Endodontics

AI has found extensive applications in endodontics, benefiting various aspects of clinical practice, and patient experience. Some notable applications include:

Clinical Applications

1. **Computer Vision in CBCT Scans [**71].

AI-powered computer vision aids in the analysis of Cone Beam Computed Tomography (CBCT) scans, helping identify anatomical structures, cracks, and pathologies, thereby assisting in treatment planning.

2. **Metal Artifact Reduction Filters [**72].

AI algorithms reduce image distortion caused by metallic restorations or implants in CBCT scans, improving the clarity and accuracy of interpretation.

3. **Diagnosis Support [**73].

AI models analyze patient data, including radiographic images, clinical history, and symptoms, to assist endodontists in making accurate diagnoses and treatment recommendations.

Patient Experience

1. **Chatbots on Practice Websites [**74].

AI-driven chatbots provide instant responses to patient queries, assist with appointment scheduling, and deliver relevant educational resources, enhancing patient engagement and satisfaction.

Ongoing research aims to expand the applications of AI in endodontics, including automated analysis of histopathological samples, crack detection, predicting treatment outcomes based on patient characteristics, and personalized treatment planning. In conclusion, AI is transforming endodontics by improving clinical decision-making, streamlining practice management, and enhancing the overall patient experience. Its potential applications range from detecting periapical pathosis, root fractures, and determining working length to predicting disease outcomes. However, there is a critical need for high-quality evidence to assess the reliability, applicability, and legal/ethical considerations of AI in endodontics [75].

Furthermore, AI has demonstrated success in early diagnosis of dental caries, reducing the necessity for invasive treatments. Its accuracy in identifying interproximal caries, assessing endodontic complications, detecting periapical lesions, and evaluating root canal morphology highlights its effectiveness. As AI continues to advance, it has the potential to further enhance diagnostic capabilities and treatment planning in the field of endodontics.The applications of AI in various dental specialties indeed showcase its potential to enhance diagnosis, treatment planning, and overall patient care in dentistry. However, there are notable challenges related to the awareness and implementation of AI in the dental field [76].

1. **Lack of Knowledge and Awareness**
   - Many dental surgeons may not be fully aware of the intricacies and capabilities of AI in dentistry. There might be a lack of knowledge regarding how AI techniques, such as machine learning and deep learning, work and their potential applications in dental practice.

2. **Limited Experience in Implementation**
   - The implementation of AI in dental practices requires a certain level of expertise and experience. Integrating AI technologies into existing workflows, interpreting AI-driven analyses, and utilizing AI tools effectively may pose challenges for dental professionals who are not familiar with these technologies [77].

Addressing These Challenges May Involve

- **Educational Initiatives**

Establishing educational programs to increase awareness among dental professionals about the applications and benefits of AI in dentistry. Workshops, seminars, and online courses can contribute to knowledge dissemination.

- **Training Programs**

Offering specialized training programs to dental surgeons to familiarize them with the practical aspects of implementing AI in their daily practice. This could include hands-on training sessions and case studies.

Collaboration and Networking

Encouraging collaboration between dental professionals and experts in AI and technology. Networking opportunities and partnerships can facilitate knowledge exchange and provide guidance on successful AI integration.

- **Continuing Education**

Promoting continuous learning and staying updated on advancements in AI technologies through ongoing education opportunities. This can help dental professionals adapt to evolving trends and incorporate AI seamlessly into their practice.

Ultimately, addressing the lack of knowledge and experience regarding AI in dentistry is crucial for realizing the full potential of these technologies in improving patient outcomes and advancing dental care. As awareness grows and educational initiatives expand, dental professionals are likely to become more adept at leveraging AI tools for enhanced diagnosis and treatment planning [78].

AI is seen as a supportive technology that can assist healthcare professionals in making more informed decisions, optimizing workflows, and improving overall patient care. The synergy between AI and human expertise is considered a powerful combination in advancing healthcare practices. The constant evolution of the healthcare sector involves the integration of new technologies, and AI is one of the innovative tools contributing to this transformation. By leveraging AI, healthcare professionals can enhance the efficiency of diagnoses, receive valuable insights from data analysis, and provide more personalized and effective treatment recommendations.

However, it is essential to acknowledge that various studies showcasing the potential of AI in healthcare have been conducted in experimental or controlled settings. To fully validate and integrate AI applications into clinical practice, further research, validation studies, and real-world implementations are necessary. This ongoing research and validation process are critical to ensuring the reliability, accuracy, and ethical use of AI technologies in healthcare. In summary, the integration of AI in healthcare is a dynamic process aimed at improving patient care, and while advancements are promising, ongoing research and collaboration are essential to validate and responsibly implement AI applications in clinical practice.

CONCLUSION

The use of AI in dentistry has indeed shown promising results across various dental specialties, and its application has demonstrated advantages in decision-making processes. The key points that support the positive outcomes associated with AI in dentistry:

1. **Accuracy Equivalent to Trained Specialists**

Studies have indicated that AI models in dentistry can achieve accuracy levels comparable to those of trained dental specialists, suggesting that AI systems can effectively analyze diagnostic data and assist in decision-making with a high degree of precision.

2. **Overcoming Human Errors**

AI models are designed to minimize or overcome human errors by processing large volumes of data consistently and objectively. This capability reduces the likelihood of errors that may arise from factors such as fatigue or variability in human judgment.

3. **Improved Outcomes in Dental Treatments**

The integration of AI in dental practice has the potential to lead to better treatment outcomes. AI can aid in diagnostics, treatment planning, and even personalized treatment recommendations, contributing to more effective and tailored care for patients.

4. **Time Efficiency**

AI has the capability to streamline various aspects of dental procedures, leading to time efficiency. Automated processes and analysis can expedite tasks, allowing dental professionals to focus on critical aspects of patient care.

5. Enhanced Comfort for Patients and Professionals

The implementation of AI technologies can contribute to a more comfortable experience for both patients and dental professionals. From faster diagnostics to improved treatment planning, AI can create a smoother and more efficient workflow.

In summary, the potential of artificial intelligence in dentistry is promising, with benefits such as improved patient outcomes, optimized treatment processes, and increased efficiency. As technology progresses, widespread integration of AI in dental practices is anticipated, benefiting both professionals and patients. Continued research and validation are crucial to ensure the responsible and effective use of AI in dentistry.

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