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OVERVIEW ON ARTIFICIAL INTELLIGENCE IN DENTISTRY

Dentistry

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ABSTRACT

Artificial Intelligence (AI) is transforming the field of dentistry by improving diagnostic accuracy, customizing treatment approaches, and enhancing patient outcomes across diverse dental disciplines. AI-driven technologies, including machine learning and deep learning, are increasingly applied in areas such as radiographic interpretation, cavity detection, prosthodontics, periodontics, orthodontics, oral surgery, pathology, and pediatric dentistry to streamline clinical processes and boost effectiveness. However, the widespread implementation of AI faces challenges related to data security, algorithmic fairness, ethical issues, and a lack of comprehensive regulations. The future development of dentistry will involve integrating AI with advanced tools like augmented reality (AR) and virtual reality (VR) to enable more tailored and predictive dental care, while prioritizing openness and patient confidence. Achieving successful AI integration requires close cooperation among dental professionals, technology experts, and regulatory bodies to address ethical and legal concerns and foster responsible innovation for improved global oral health.

KEYWORDS

INTRODUCTION

Artificial Intelligence (AI) is driving a global transformation across various industries by introducing innovative tools that improve operational efficiency, enhance decision-making capabilities, and enrich user interaction. In today's digital era, AI stands out as a groundbreaking technology with far-reaching applications in sectors like finance, transport, education, and, most prominently, healthcare. Within healthcare, dentistry is rapidly advancing as a key area where AI is making a notable impact. From enabling faster diagnostics to tailoring treatment strategies and elevating patient care, AI is fundamentally changing the landscape of dental practice.

AI is typically described as the ability of machines, especially computers, to perform tasks that normally require human intelligence. These tasks include learning from data, reasoning, solving problems, interpreting sensory input, and understanding language. While the roots of AI go back to the 1950s, it is only with recent breakthroughs in machine learning and data science that AI has become a practical tool in clinical settings. The concept of artificial intelligence was formally introduced in 1956 by John McCarthy during the Dartmouth Summer Research Project, an event widely considered the foundational moment for the field of AI within computer science [1].

This essay will examine how AI is being integrated into contemporary dentistry, highlight its applications across different branches of the field, explore its potential advantages and limitations, and consider the ethical, technological, and regulatory issues that arise with its use.

The dental profession has embraced artificial intelligence with growing enthusiasm. The integration of AI into dental practices is transforming traditional methods, enhancing diagnostic accuracy, personalizing treatment plans, and improving patient outcomes. This technological advancement is not only streamlining clinical workflows but also democratizing access to quality dental care. AI has the ability to completely transform clinical practice by increasing dental care's overall effectiveness and improving patient outcomes. AI is being used in dentistry in a number of important areas, such as image analysis, patient management, diagnosis, treatment planning, and individualized care.

AI has evolved far beyond its early ambition of simulating human cognition. Today, with powerful machine learning and deep learning architectures especially convolutional neural networks (CNNs) dentistry is experiencing a leap forward in diagnostic accuracy, automation, and patient centred care. These advances are not mere enhancements; they redefine the standard of what is possible in dental practice. The cornerstone of AI integration in dentistry lies in radiologic and imaging analysis. Deep learning models can sift through thousands of panoramic radiographs, cone beam computed tomography (CBCT) scans, and intra-oral snapshots at speeds and proficiency unmatched by human readers.

APPLICATION OF AI IN DENTISTRY

Advancing tools of AI has vast applications in different fields of dentistry. Starting with the radiographic image analysis, Research featured in peer-reviewed journals has shown that AI systems are highly effective in detecting and segmenting structures in oral and maxillofacial CBCT scans, demonstrating strong accuracy in these diagnostic tasks. Artificial intelligence-based systems seem to have the potential to streamline oral and dental healthcare services and facilitate preventive and personalized dentistry [2]. Meta-analytic findings suggest that AI tools can drastically shorten the time required for tooth segmentation up to tenfold compared to manual methods thus enhancing clinical workflow efficiency and precision in dental imaging. AI based models achieve high accuracy in delineating tooth boundaries from CBCT images, reducing reliance on manual methods [3].

Besides analysing radiographs, AI is also advancing rapidly in the field of diagnostic dentistry. Software powered by AI can deliver precise and reliable diagnoses of dental cavities using intraoral X-rays, achieving performance levels that meet or surpass set standards. A systematic review and meta-analysis covering 21 studies on AI for caries detection found that convolutional neural networks exhibit “excellent accuracy, sensitivity, and specificity” in fourteen of these studies, although their performance may vary in practical applications [4]. Parinitha et al. highlighted that the use of AI in endodontics is a transformative development, boosting both diagnostic accuracy and the success of treatments. AI enables detailed examination of root canal anatomy and helps predict the results of retreatment procedures. Its capacity to detect small abnormalities and improve working length measurement underscores its essential role in advancing endodontic care [5]. These AI systems act not just as a second opinion but also support decision-making in uncertain situations, boosting diagnostic confidence. Additionally, AI-powered diagnostic platforms can continuously adapt and improve, becoming more accurate as they process more data.

In prosthodontics, AI is valuable for tasks such as margin detection, tooth preparation, occlusal morphology analysis, shade selection, aesthetic enhancements, and error detection. It also plays a key role in predicting implant success and creating digitally advanced maxillofacial prostheses [6]. In the 1980s, Dr. Werner Mormann and Marco Brandestini brought the first CAD/CAM system into a dental clinic at the University of Zurich, initiating the integration of AI into dentistry. This innovation transformed dental practice by enabling the production of multiple ceramic restorations directly in clinics and labs. Using scans of a patient's existing teeth, CAD/CAM technology allows for the creation of personalized 3D models of dental crowns tailored to individual needs. AI assists in analyzing intraoral scans to design and produce crowns, bridges, dentures, and implants, enhancing both the precision of fit and overall aesthetics [7].

AI has shown potential in enhancing the detection of periodontitis,

including its various forms and links to systemic conditions. In a study by Lee et al., a computer-aided diagnosis (CAD) system utilizing a deep convolutional neural network (DCNN) was used to identify and predict teeth affected by periodontal issues. The CNN achieved diagnostic accuracy rates between 76.7% and 81.0% for periodontally compromised teeth (PCTs), and between 73.4% and 82.2% in predicting the need for tooth extraction. Accuracy varied by tooth type, with premolars identified as PCTs more accurately than molars (82.8% vs. 73%). This difference is likely due to the simpler anatomy of premolars, which typically have a single root, compared to the more complex, multi-rooted structure of molars, making them more challenging for the CNN to interpret [8]. Krois et al. employed convolutional neural networks (CNNs) to identify periodontal bone loss through the analysis of panoramic dental X-rays [9].

AI is transforming orthodontics using advanced algorithms and machine learning models, AI enhances the accuracy of tooth movement predictions, allows for precise customization of aligners, shortens treatment duration, supports real-time monitoring, and improves overall treatment planning through detailed 3D visualization. Patil et al. revealed AI-powered automated image analysis accurately monitors orthodontic tooth movement, minimizing the need for time-intensive manual evaluations. In a study involving 100 patients, AI demonstrated 92% precision with an error margin of just 0.25 mm and closely matched manual measurement results. Each image set was analysed by AI in just 3 seconds, compared to the 7 minutes required for manual assessment. Orthodontists rated the reliability of AI at 4.7 out of 5, with 86% favouring AI-assisted tracking. This highlights AI's ability to improve treatment efficiency, consistency, and clinical decision-making [10].

Artificial Intelligence (AI) is significantly advancing the field of oral and maxillofacial surgery (OMFS) by refining diagnostic capabilities, optimizing surgical planning and navigation, and elevating the standard of patient care. Tools such as machine learning (ML), deep learning (DL), and convolutional neural networks (CNNs) are driving greater accuracy, efficiency, and improved clinical results in this highly specialized area of surgery. The use of 3D imaging, virtual surgical planning, digital facial and oral scanning, along with 3D printing of models and surgical guides, has supported surgeons across multiple areas of practice. Over the years, the steady incorporation of computer-aided technologies has helped streamline surgical workflows and improve the precision of patient outcomes [11]. Rokhshad et al. Studies have demonstrated that AI can reliably predict the outcomes of rhinoplasty and assess the likelihood of future orthognathic surgery in cleft patients.[12]

AI is increasingly influencing oral pathology by delivering highly accurate image analysis, improving workflow efficiency, enabling structured reporting, and supporting outcome prediction. Although challenges remain in areas like data standardization, validation, and ethical considerations, these technologies show strong potential to make patient care more effective, dependable, and personalized. To successfully integrate AI into routine clinical use, collaboration among pathologists, AI experts, and regulatory bodies is essential. Reported results from a systemic review demonstrated strong deep learning (DL) performance, with accuracy ranging from 85% to 100% in oral cancer studies, indicating its potential to enhance informed clinical decision-making in oral cancer management [13]. Convolutional neural network (CNN) models have shown potential in detecting oral squamous cell carcinoma (OSCC) and oral potentially malignant disorders (OPMDs) using photographic images of the oral cavity. Warin k. et al. models are expected to become valuable diagnostic tools to support general practitioners in the early identification of oral cancer [14].

AI is reshaping paediatric dental care by utilizing machine learning, deep learning, and predictive analytics to improve early diagnosis, customize treatment planning, manage patients more effectively, and provide targeted preventive care for children. A systematic review [15] has demonstrated that virtual reality (VR) technology is an effective method for reducing anxiety and pain in children during dental procedures, outperforming traditional behavioural management approaches. By offering an immersive and interactive experience, VR helps divert children's attention from the clinical setting, leading to a more comfortable and pleasant treatment experience.

BARRIERS & CHALLENGES

Although artificial intelligence (AI) has made promising progress in dentistry, there are still notable challenges and limitations that prevent its broad implementation. A key issue is data privacy and security, as AI relies on vast amounts of patient information to function effectively, yet this sensitive data is at risk of being compromised or misused without proper safeguards. A major challenge in applying AI to dentistry is the limited availability and quality of data. Deep learning models, in particular, need large amounts of diverse and well-labelled data to accurately identify patterns. However, dental datasets are often scarce, and many are biased toward certain populations or clinical situations, which can reduce the effectiveness and reliability of AI tools when used with a wider and more diverse patient population [16]. Surlari Z et al. pointed out that AI technology and its user interfaces require further refinement. Several important intermediate milestones must be reached before AI can be broadly implemented [17]. Significant ethical issues continue to pose obstacles to the adoption of AI in healthcare. A review of 39 studies highlighted key ethical challenges, including concerns about privacy, trust, informed consent, and potential conflicts of interest [18]. Ahmed MI, et al. reviewed Forty-two studies addressed challenges related to data, such as issues with data quality, limited access to data, and the size of available datasets [18]. A significant concern is the issue of informed consent patients may not fully grasp how AI technologies are being applied in their treatment or to what extent algorithmic recommendations influence clinical decisions. This opacity can undermine patient autonomy. Another major challenge is determining accountability: when an AI system contributes to a misdiagnosis or an unsatisfactory treatment result, it is often unclear whether responsibility lies with the software developer, the dental professional, or the healthcare institution. Additionally, biases in algorithms often caused by training data that fails to represent diverse populations can result in disparities in care, particularly affecting minority groups or individuals with less common dental conditions. Therefore, it is crucial to prioritize data quality, transparency, and equity in the design and implementation of AI models. The lack of standardized legal regulations governing the use and oversight of AI in dentistry further complicates these issues, highlighting the urgent need for updated policies that both safeguard patients and support technological advancement in the field. While AI offers significant potential in forecasting, diagnosing, guiding clinical decisions, tailoring treatment plans, and managing patient care, its successful implementation requires careful attention to ethical considerations [19].

Patient acceptance plays a vital role in the effective adoption of AI within dental care. Research shows that although many patients appreciate AI's ability to enhance diagnostic precision and tailor treatments, worries about data privacy, loss of personal touch in care, and the clarity of AI-driven decisions continue to pose major challenges [20].

Future Prospects

The future of AI in dentistry looks bright and is set to experience remarkable progress, driven by ongoing enhancements in machine learning techniques, data collection, and the fusion with other advanced technologies. A key development is the move toward personalized and predictive dental care, where AI will utilize extensive datasets including clinical records, genetic profiles, and lifestyle factors to create tailored risk evaluations and customized treatment strategies. A major focus is combining AI with new technologies such as augmented reality (AR) and virtual reality (VR), which can significantly improve surgical planning, patient education, and provide more immersive training opportunities for dental professionals [21]. Additionally, progress in AI seeks to improve transparency, enabling both clinicians and patients to more clearly comprehend AI-generated recommendations, which in turn boosts trust and supports informed consent [18]. Lastly, cooperation among AI researchers, dental experts, and regulatory authorities is crucial to develop standardized protocols and regulations that both protect patient safety and encourage innovation [17]. In general, the future of AI in dentistry anticipates a move toward more efficient, precise, and patient-focused care, with the potential to revolutionize oral health outcomes worldwide.

Artificial Intelligence (AI) is no longer a distant prospect it is actively reshaping dental care across a range of specialties. Whether it's interpreting radiographs, assessing root canal treatments, planning orthodontic procedures, designing prosthetics, or detecting oral diseases, AI is enhancing clinical precision and elevating standards of

care. These innovations lead to more accurate diagnoses, tailored treatments, minimized errors, and streamlined workflows. Beyond improving clinical efficiency, AI also offers new avenues for expanding access to dental services such as through teledentistry and for enriching patient education and engagement using tools like virtual and augmented reality.

Despite its promise, AI also introduces complex challenges. Key concerns include data integrity, algorithmic bias, privacy, ethical clarity, and legal responsibility. To fully integrate AI into everyday dental practice, it is crucial to address these issues. Ensuring patient consent, upholding autonomy, and creating transparent, explainable AI systems are not just regulatory hurdles they are moral obligations. Moving forward, collaboration between dental professionals, technologists, educators, and policymakers is vital to develop responsible, inclusive, and effective AI frameworks.

CONCLUSION

In conclusion, artificial intelligence is not just advancing dental care it is revolutionizing it by reshaping clinical workflows, patient interactions, and professional education. AI enhances accuracy in diagnosis, boosts treatment effectiveness, and increases accessibility through tools like teledentistry and virtual reality, offering wide-reaching benefits across the dental field. Yet, the true success of AI integration relies on more than just technical capability. Ethical practices, transparency, patient confidence, and inclusive development must take center stage to ensure fair and responsible use. As AI becomes a core element of dentistry, collaboration among dental experts, technologists, educators, and policymakers will be vital to steer progress in a direction that upholds both innovation and compassion. Moving forward, the focus must remain not only on what AI *can* achieve, but on how it *should* be applied to promote safer, better, and more equitable oral healthcare.

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