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International Journal of Head and Neck Pathology

Review Article

ARTIFICIAL INTELLIGENCE IN DENTISTRY

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How to cite: Sivakumar G, Artificial Intelligence in Dentistry. Int J Head And Neck Pathol 2024; 7(1):07-14.

DOI: *https://doi.org/10.56501/intjheadneckpathol.v7i1.1113*

Received:13/02/2024 *Accepted:23/02/2024* *Web Published:25/03/2024*

Abstract

Artificial intelligence (AI) is transforming dentistry by improving diagnosis accuracy, treatment planning, and patient outcomes. AI systems evaluate radiographs, intraoral scans, and patient data to detect dental problems with great precision, often outperforming humans. Machine learning models predict the outcomes of various treatments, allowing dentists to make informed judgments. AI-powered applications make administrative duties easier, from arranging appointments to managing patient records, resulting in greater operational efficiency. Furthermore, AI-powered virtual assistants offer individualized patient education and support, promoting improved oral health habits.

Despite these advancements, there are still issues like data security, integrating with current dental procedures, and the requirement that dental professionals undergo intensive training. The abstract comes to the conclusion that although artificial intelligence (AI) can thrust dentistry into the futuristic realm, its successful implementation in the industry will depend on continued research and development as well as ethical and legal issues.

Keywords: artificial intelligence, machine learning, dental education

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INTRODUCTION

The human brain, an incredibly intriguing aspect of the human body, has consistently captivated the curiosity of scientists and researchers. Despite considerable efforts, the scientific community has yet to comprehend the intricacies of constructing a flawless model that accurately replicates the functions of the human being [1].

Since the inception of the scientific field, scientists and technologists have dedicated their efforts to unraveling the complexities of the human neural network—a labyrinth of interconnected neurons acting as gateway of neurons throughout the entire body. Crafting a model that faithfully simulates the multidimensional human brain is a herculean task for the scientific community. The continuous dedication and imagination of researchers over the years have led to the conception of 'Artificial Intelligence' [2].

In 1956, John McCarthy pioneered the field of applied computer science, coining the term "artificial intelligence" (AI). Occasionally referred to as machine intelligence, AI is considered a vital component of the "fourth industrial revolution." This revolution leverages computer technology to emulate human-like critical thinking, decision-making, and intelligent behavior[1].

The overarching objective of artificial intelligence is to facilitate automated learning without the need for human intervention. AI models are designed to predict future events based on the current set of observations, aiming to achieve a level of autonomy in decision-making and problem-solving processes [3].

The applications of Artificial Intelligence technologies, such as Natural language processing, Image recognition, Expert systems, Gameplaying, Theorem-proving, and Robotics, have experienced significant growth in various fields, including telecommunication and aerospace. The impact of technology has been particularly revolutionary in the realms of medicine and dentistry over the last decade [4].

KEY ELEMENTS OF ARTIFICIAL INTELLIGENT SYSTEM:

Understanding the important tenets of artificial intelligence systems in today's environment is essential, as illustrated in Fig 1.Artificial intelligence refers to a machine's capacity to demonstrate intelligence by solving problems through the analysis and interpretation of data learning involves the use of algorithms to predict outcomes from a given set of data. The objective is to enable machines to learn from data and address problems without requiring direct human intervention, streamlining the learning process for the machine.

Neural networks process signals by utilizing artificial neurons that function in a manner similar to the human brain.

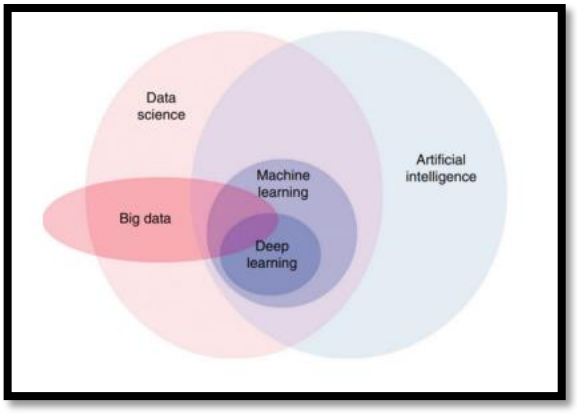

Fig 1: Key elements of artificial intelligent systems[5]

Deep learning, with its multiple computational layers, constructs a neural network capable of automatically recognizing patterns and enhancing feature detection. In the medical field, deep learning algorithms have demonstrated a high level of accuracy in diagnostics. However, there has been limited progress in addressing specific dental problems. Consequently, a comprehensive examination is needed for dental studies. The present state and effectiveness of AI in dental applications remain to be thoroughly documented and analyzed. As a result, this current review delves into the utilization of AI and machine learning algorithms in the context of dental diseases and diagnostics [5,6].

Data science is the systematic approach of examining and extracting valuable insights from data. Big data provides users with accurate information by assessing a vast set of data that has been continually growing for years at the right time [5].

SUBFIELDS OF ARTIFICIAL INTELLIGENCE:

AI encompasses numerous subfields, as illustrated in Fig 2. These subfields are frequently integrated into solutions to address various problems.

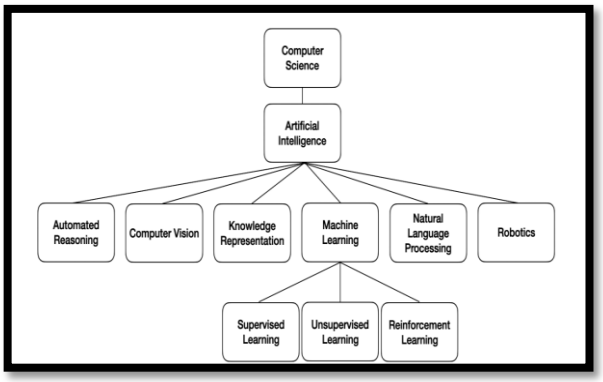

Fig 2: Subfields of artificial intelligence[7].

MACHINE LEARNING:

Machine Learning (ML), a subset of AI, utilizes algorithms to execute tasks by learning patterns from data. This technique involves adjusting parameters based on the underlying method, such as the number of neurons and layers in a neural network, or the population size, mutation rate, and crossover rate in genetic algorithms. ML models like Genetic Algorithm, Artificial Neural Network (ANN), and Fuzzy Logic can learn and analyze data to perform various functions. Among these, the Artificial Neural Network (ANN) stands out as one of the most popular models [2].

Artificial Intelligence techniques show significant potential for detecting and diagnosing oral cavity abnormalities that may go unnoticed by the human eye, leading to their integration into orthodontic care. Within dentistry, machine learning algorithms and deep learning techniques, such as Artificial Neural Networks (ANN), Convolutional Neural Networks (CNN), Genetic Algorithms (GA), and Fuzzy Logic, are among the AI approaches employed for various application [5,7].

ROLE OF ARTIFICIAL INTELLIGENCE SYSTEMS IN DENTAL EDUCATION:

AI has revolutionized the field of dental education by establishing high-quality training environments. Students now have the opportunity to conduct their preclinical work on virtual patients instead of relying on phantom heads or simulators. These virtual patients are interactive, enhancing the efficiency of preclinical tasks and mitigating the risks associated with working on live patients [8].

ROLE OF ARTIFICIAL INTELLIGENCE IN DIAGNOSIS AND TREATMENT:

AI has revolutionized field of diagnosis. With simple mobile applications, pictures of lesion can be uploaded in the application and diagnosis can be made by comparing the pictures from the vast data available around the world. Thus, doctors can prioritize the appointment when necessary and patients have easy access to expert opinion. Artificial intelligence can be useful in screening and diagnosing suspicious oral lesions into premalignant and malignant lesions.AI provides both qualitative and quantitative data based on data input to the practitioner and thus improving accuracy in early detection, diagnosis, treatment planning [8,9].

APPLICATIONS IN THE VARIOUS FIELDS OF DENTISTRY:

Today, artificial intelligence-based virtual dental assistants are readily available in the market. These software applications, serving as virtual assistants, exhibit the capability to perform a variety of simple tasks in dental clinics with greater precision, reduced manpower requirements, and fewer errors compared to their human counterparts. Some of the tasks that these virtual dental assistants can efficiently handle includes:

- Booking and coordinating regular appointments based on the convenience of both patients and dentists
- Providing alerts to both patients and dentists for checkups whenever genetic or lifestyle information indicates an increased susceptibility to dental diseases. For instance, sending reminders for periodontal screening to patients with diabetes or oral cancer screening for individuals who habitually use smoked or smokeless tobacco
- Efficiently managing paperwork and insurance-related tasks in the dental clinic.
- Aiding in clinical diagnosis and treatment planning by providing valuable insights and support based on artificial intelligence algorithms
- Providing alerts to the dentist prior to each appointment regarding any allergies that the patient may have, ensuring proactive consideration of potential concerns during the dental visits.
- Patients alerts to the dental healthcare provider about pertinent medical history, such as the use of prophylactic antibiotics in patients who have undergone cardiovascular surgeries. This ensures that the healthcare provider is informed of relevant details for enhanced patient care.
- Establishing regular reminders for patients enrolled in tobacco or smoking cessation programs, promoting consistent engagement and support for individuals undergoing such initiatives
- Offering emergency tele-assistance in situations of dental emergencies when the dental healthcare professional cannot be immediately reached, providing guidance and support remotely [4].

ARTIFICIAL INTELLIGENCE IN ORAL PATHOLOGY:

Head and neck cancer ranks among the top 10 most prevalent cancers globally, with an estimated 150,000 new cases reported annually. The prognosis for advanced stages is unfavorable, displaying a five-year survival rate of only 40%. However, this rate significantly improves to 80-90% with early diagnosis. Oral squamous cell carcinomas (OSCCs) affecting the oral cavity are particularly common. Lesions in the oral mucosa showing dysplasia are statistically more likely to progress into OSCC compared to non-dysplastic lesions. Additional risk factors for the transition to malignancy include sex, the site or type of lesion, and habits such as tobacco and alcohol consumption [10].

The diagnosis and grading of oral epithelial dysplasia (OED) can be conducted using various classification systems. The criteria established by the World Health Organization (WHO) in 2017 are widely regarded as the gold standard. This classification system categorizes OED lesions as mild, moderate, or severely dysplastic, taking into account both cytological and architectural features for assessment [10].

Recent advancements in digital pathology have facilitated the digitization of histology slides, transforming them into whole slide images (WSIs) through high-resolution digital scanners. This progress has contributed to a substantial expansion of the field of computational pathology [10,11].

In pathology, deep learning techniques have been applied to automatically segment the epithelium in various histology images, including those from oral, cervical, and prostate tissues. Additionally, these techniques have been utilized to further segment and classify individual nuclei within whole slide images (WSIs). Specifically in the context of oral epithelial dysplasia (OED), deep learning has been employed to segment the epithelium into sub-regions, distinguishing the lower basal layer, the middle epithelial layer, and the superior keratin layer [11].

The network proposed in this study is built upon Hover-Net, a model designed for nuclear instance segmentation and classification. HoVer-Net features a single encoder branch and three decoder branches, allowing for simultaneous nuclear instance segmentation and classification. Notably, it has demonstrated state-of-the-art (SOTA) performance across various H&E stained histology image datasets, showcasing its adaptability to different histology images and pathologies. In this specific research, HoVer-Net is utilized for nuclear segmentation and classification. The hypothesis is further explored, suggesting that the inclusion of an additional decoder branch for layer segmentation may enhance both nuclear and layer classification [11].

The term digital pathology was initially coined to encompass the process of digitizing Whole Slide Images (WSIs) using advanced slide-scanning techniques. Now, it also refers to artificial intelligence (AI)-based approaches for the detection, segmentation, diagnosis, and analysis of digitized images. Notably, the first large-scale multicenter comparison of diagnostic performance between digital pathology and conventional microscopy was conducted in a comprehensive study by Mukhopadhyay et al. This study, which included specimens from 1,992 patients with various tumor types and involved 16 surgical pathologists, demonstrated that primary diagnostic performance with digitized WSIs was non-inferior to that achieved with traditional microscopy-based approaches. The major discordance rate from the reference standard was reported to be 4.9% for WSI and 4.6% for microscopy in this study [11].

In cancer, the intricate genomic alterations influencing cell signaling and cellular interactions with the environment can significantly impact the biological trajectory of the disease and influence responses to therapeutic intervention.

Therefore, AI-based approaches, known for their robustness and reproducibility, serve as a foundation for addressing some of the challenges encountered by oncologists and pathologists. This assertion is substantiated by the findings of several studies, indicating that AI-based approaches exhibit a comparable level of accuracy to that of expert pathologists [11,12].

IN DENTAL RADIOLOGY:

AI brings an additional dimension to the learning capabilities of dental professionals [2]. With an increasing emphasis on diagnostic procedures involving digital RVGS/IOPA, 3D scans, and CBCT, AI is progressively integrating into radiology within dentistry. Developing an AI system for swift diagnosis and treatment planning necessitates the acquisition and processing of substantial amounts of data.[1] For instance, dental professional teams utilize Artificial Neural Networks (ANN) to precisely localize minor apical foramen, thereby enhancing the accuracy of working length determination in radiographs and aiding in the diagnosis of proximal caries [2].

IN ORAL AND MAXILLOFACIAL SURGERY:

The significant use of artificial intelligence in oral surgery is evident in the development of robotic surgery, where human body motion and intellect are replicated. This technology finds application in various oral surgical procedures, including dental implantation, tumor and foreign object removal, biopsies, and temporomandibular joint (TMJ) surgery. Image-guided cranial surgery procedures have demonstrated success in clinical settings. Comparative studies in oral implant surgery highlight significantly improved accuracy when compared to freehand procedures, even when conducted by skilled surgeons. Generally, the benefits reported include reduced operation time, enhanced intraoperative accuracy, and safer manipulation around delicate structures [1].

IN PROSTHETIC DENTISTRY:

The application of AI technologies in prosthodontics has been demonstrated through automated diagnostics, predictive measures, and as a classification or identification tool. The research findings suggest that, within the broader field of prosthodontics, AI has been utilized in areas such as CAD/CAM systems, implant prosthetics, tooth preservation, and orofacial anatomy. Despite these potential applications, the use of AI technology in prosthodontics is still relatively uncommon [13].

A design assistant named RaPid, developed for application in prosthodontics, integrates various factors such as anthropological calculations, face dimensions, ethnicity, and patient preferences to provide patients with the optimal aesthetic prosthesis. RaPid connects databases, knowledge-based systems, and computer-aided design through a logic-based representation as a unifying framework. Leveraging advancements in neural networks, laboratories are now employing AI to autonomously generate innovative dental restorations that meet rigorous standards for fit, function, and aesthetics [1].

IN ORTHODONTICS:

A notable recent innovation in orthodontics is the introduction of personalized orthodontic care powered by AI. AI is now utilized for orthodontic diagnosis, planning, and treatment monitoring. Radiographs and images captured by intraoral scanners and cameras can be analyzed for accurate diagnosis and treatment planning. This eliminates the need for multiple laboratory procedures, as well as traditional patient impressions, and the results often surpass the precision of human perception.[1] 3D scans and virtual models play a crucial role in assessing craniofacial and dental abnormalities. These scans enable the creation of customized aligners, printed based on the patient's unique needs. An AI algorithm is then developed to intelligently determine how the teeth should be moved, the amount of pressure to be applied, and even identify specific pressure points for each tooth.[2] AI-assisted aligners hold the promise of reducing treatment times, streamlining appointment schedules, and ensuring precise treatment execution and progress [1].

IN FORENSIC ODONTOLOGY:

AI has made significant strides in forensic medicine, proving effective in determining the biological age and gender of individuals, both healthy and ill. It is also utilized for analyzing bite marks and predicting mandibular morphology. A recent innovation in dentistry involves a voice-command dental chair, eliminating the need for physical manipulation by the doctor. Voice commands can be employed for various operations, and future advancements may enable dental chairs to monitor vital signs, anxiety levels, weight, and procedure duration. This intelligent technology could provide comfort to patients, alert operating doctors to any variations, and more. AI is also making creative contributions in the field of "bio printing," allowing the creation of living tissue and organs in successive thin layers of cells. This innovation holds potential for reconstructing oral hard and soft tissues lost due to pathological or unintentional causes [1].

IN PERIODONTICS:

Wang et al. introduced a Digital Convolution Neural Network system, featuring 16 convolution layers and two fully connected layers, for the detection of periodontitis in premolars and molars. Additionally, Artificial Neural Networks (ANN) prove effective in categorizing patients into aggressive periodontitis and chronic periodontitis based on their immune response profile. Despite various applications of AI in dentistry, one of the most prevalent and user-friendly advancements is seen in dental chairs. The evolution from conventional hydraulic chairs to electrical and fully automatic dental chairs, operated through sensors, and highlights how AI has significantly transformed the dental chair used by dentists throughout their daily practices [2].

IN ENDODONTICS:

AI plays a crucial role in detecting dental caries on radiographs, providing valuable assistance to clinicians. Fatigue or variations in clinical training can sometimes lead to the oversight of carious lesions by clinicians. Additionally, errors in perception and cognitive challenges in classifying health and disease can pose obstacles in diagnosing and treating caries. AI serves as a solution to overcome these challenges, offering a more consistent and objective approach to caries detection. By leveraging AI technologies, clinicians can enhance the accuracy and efficiency of their diagnostic processes [8].

Several studies have investigated the automated detection of periapical radiolucencies using Orthopantomograms (OPGs) or Cone Beam Computed Tomography (CBCT). Computer vision and neural networks contribute to interpreting CBCTs in a manner that surpasses human vision. The early detection of periapical lesions through automated methods holds the potential to prevent complications and enhance patient outcomes [7].

Detecting Vertical Root Fractures (VRFs) poses a critical clinical challenge, particularly when these fractures lead to the deterioration of adjacent bone. In such instances, the extraction of the affected tooth becomes imperative. Conversely, cases involving periradicular chronic inflammatory processes or periradicular cystic lesions may be addressed through apical root resection. Consequently, the accurate pre-operative identification of a fracture plays a pivotal role in determining appropriate therapeutic strategies [14].

In the current research, a Probabilistic Neural Network (PNN) has been developed to diagnose VRFs using periapical and Cone Beam Computed Tomography (CBCT) images. The study focuses on both endodontically treated and intact premolars devoid of caries. This innovative approach involves advanced imaging techniques to enhance the detection and diagnosis of VRFs, aiming to provide a reliable method for early identification. The differentiation between cases requiring tooth extraction and those where apical root resection suffices underscores the significance of precise pre-operative detectionin guiding subsequent treatment decision [14].

IN PEDODONTICS:

In the era of the global epidemic, a significant portion of the child population is affected by oral problems. Ensuring a child's optimal health requires early identification, prevention, and treatment of these issues. Within the dental field, there is a growing demand for professionals who can effectively administer treatment while also providing appropriate counseling on patient behavior, especially in pediatric dental care. Artificial Intelligence (AI) has emerged as a crucial player in demonstrating its advantages in various pediatric dental procedures. Specifically, Convolutional Neural Network (CNN) models are employed in pediatric dentistry for quicker and more precise diagnoses. This application of AI not only facilitates improved cooperation between patients and their dental practitioners but also contributes to an enhanced success rate in dental treatment [15].

AI models play a pivotal role in various aspects of pediatric dentistry(Fig.3), providing advanced capabilities for

1. Dental plaque detection: Utilizing AI algorithms to identify and assess the presence of dental plaque, aiding in preventive oral care
2. Assessing children's oral health using machine learning tooth kits: Employing machine learning toolkits designed to assess and monitor the oral health of children, enabling more comprehensive and efficient evaluations
3. Mesiodens and supernumerary tooth identification: Leveraging AI models for the accurate identification and assessment of mesiodens and supernumerary teeth, facilitating early intervention
4. Early childhood caries detection: Using AI for early detection of early childhood caries, enabling timely intervention and prevention measures

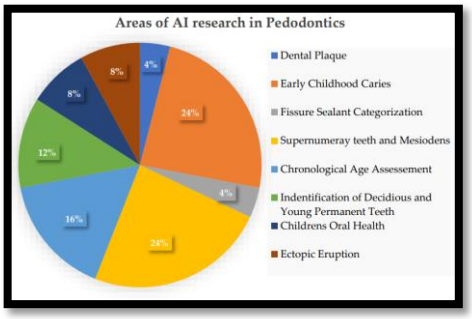

Fig 3: Areas of AI research in Pedodontics

5. Fissure and sealant categorization: Applying AI algorithms to categorize and evaluate fissure sealants, ensuring their effectiveness in preventing dental issues
6. Chronological age assessment in kids and adolescent using neural modeling: Utilizing neural modeling through AI for precise chronological age assessment in children and adolescents, aiding in treatment planning and care.
7. Detecting the deciduous and young permanent teeth: Employing AI models to identify and differentiate deciduous and young permanent teeth, contributing to accurate dental assessment
8. Ectopic eruption of first permanent molar: Using AI to detect and assess the ectopic eruption of the first permanent molar, assisting in early intervention and management.

These applications showcase how AI is revolutionizing pediatric dentistry by enhancing diagnostic accuracy, enabling early intervention, and ultimately improving the overall oral health outcomes for children [15].

BENEFITS OF AI IN DENTISTRY:

- Executing tasks in nearly no time
- Making logical and feasible decisions that lead to an accurate diagnosis.
- Standardizing procedures.

SHORTCOMINGS OF AI USE IN DENTISTRY :

- Complexity of the mechanism or system
- Expensive installation or setup.
- Necessity for sufficient training.

Data is frequently utilized for both training and testing, resulting in the potential for "data snooping bias".
The results of AI in dentistry may not be easily applicable.

CONCLUSION:

Artificial Intelligence is not a myth but represents the future of dentistry. Its applications across various domains are expanding daily. Neural networks have demonstrated performance comparable to dental experts, exhibiting enhanced accuracy and precision. In certain studies, AI models have even surpassed the proficiency of specialists. AI techniques contribute to dental practices by reducing chairside time, streamlining processes, ensuring infection control, and delivering precise, high-quality treatments. While AI is expanding the horizons of cutting-edge models in dentistry, it remains an evolving field [3].

The potential of AI approaches in digital pathology holds great promise. Over the past few years, numerous institutions globally have opted to digitize their complete pathology workflows, and the FDA approval of the Philips whole-slide scanner in 2017 represented a significant turning point toward fully digital pathology laboratories. It is essential to acknowledge that embracing such changes can be challenging, especially considering the historical reliance on the light microscope popularized by Anton van Leeuwenhoek in pathology. AI approaches are poised to play a pivotal role in the analysis and interpretation of these extensive datasets, providing valuable assistance to pathologists and oncologists in their workflow[11].

Undoubtedly, it can be asserted that AI is not meant to replace dental clinicians or pediatric dentists; instead, it serves as a valuable aid across various domains of dental health. AI plays a supportive role in every facet of dentistry, encompassing preventive dentistry, restorative dentistry, diagnostic sciences, and beyond. Its contributions lie in enhancing the efficiency and precision of tasks, aiding dental professionals in delivering improved patient care. By complementing the expertise of dental clinicians, AI contributes to more accurate diagnostics, timely interventions, and comprehensive oral health management, ultimately benefiting both practitioners and patients in the diverse realms of dental healthcare [15].

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