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Clinical Applications of Artificial Intelligence in Dentistry

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Abstract

Background: Artificial intelligence (AI) has emerged as a disruptive force in a variety of medical disciplines, including dentistry. The article presents a comprehensive overview of the clinical applications of artificial intelligence in dental sciences. AI techniques such as machine learning, deep learning, and natural language processing are quickly being applied in dentistry to improve diagnosis accuracy, treatment planning, and patient outcomes. AI algorithms have performed admirably in diagnostics, detecting and classifying oral disorders such as dental caries, periodontal diseases, and oral malignancies using a variety of imaging modalities such as dental radiography, intraoral pictures, and 3D scans. AI algorithms help clinicians generate personalised treatment plans by analysing patient data such as medical history, genetic predispositions, and treatment outcomes. These technologies help to optimize therapy procedures, improve treatment success rates, and increase patient satisfaction. Furthermore, AI-based virtual reality and augmented reality platforms allow simulation-based training for dentistry students and practitioners, boosting their skills and decision-making abilities in complex clinical circumstances. Despite AI's tremendous promise in dental sciences, some hurdles persist, including data privacy concerns, regulatory compliance, and the need for interdisciplinary collaboration. Addressing these issues is critical for maximizing the benefits of AI in clinical practice and developing dental healthcare. To summarize, the incorporation of AI technologies has enormous potential for transforming dentistry practice by enhancing diagnosis accuracy, treatment planning, and patient outcomes. Continued study, collaboration, and innovation are required to fully realize AI's potential for improving dental care delivery and increasing oral health around the world.

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Introduction

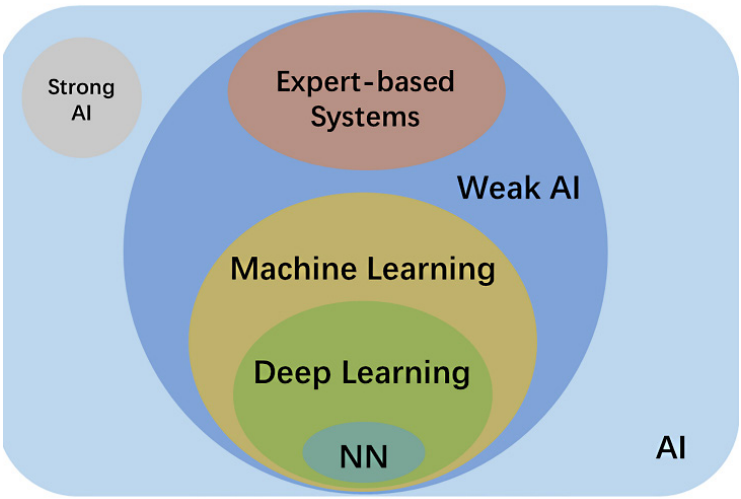
Artificial intelligence, within the realm of computer science, aims to comprehend and construct intelligent entities, often in the form of software programs. It can be defined as a sequence of operations designed to accomplish a particular task.[1] In the past, AI systems relied on manually crafted rules to tackle specific tasks, requiring expertise in the relevant domain, engineering efforts, and adjustments by experts. For instance, a system tasked with identifying abnormalities in medical images might scan for irregularly coloured masses with certain shapes, fine-tuning its parameters based on input from specialists, such as defining a range of colours for healthy tissue or setting criteria for potential masses. Presently, the medical field predominantly utilizes a subset of AI called machine learning, with deep learning emerging more recently.[2]

Machine Learning

a branch of artificial intelligence, enables systems to learn and execute intelligent tasks autonomously, without predefined rules or prior knowledge. Instead, these systems analyse large datasets to identify patterns without human intervention. Through a process called training, machine learning algorithms refine their parameters by iteratively adjusting them based on examples, gradually gaining expertise in the task at hand. This approach is comparable to teaching a child to recognize cats by showing them various pictures until they grasp the distinguishing features, which they can then apply to new images.[3]

Deep Learning

a subset of machine learning, involves computers learning not just individual patterns but also hierarchical compositions of patterns. By layering and combining these patterns, deep learning constructs complex systems that are more robust than simpler, "shallow" ones. Analogous to how a child doesn't immediately recognize a cat in a single step of pattern recognition, deep learning systems break down the process into multiple levels. Initially, they detect basic features like edges, then assemble these into more complex shapes such as eyes and ears, eventually forming larger structures like heads and legs, culminating in the recognition of the entire cat.[4]



Picture 1: Basic Structure of AI[33]

The artificial neural network (ANN)

comprised of interconnected neurons organized in layers, is a widely utilized type of deep learning technique. Typically, a neural network consists of input and output layers, with hidden layers sandwiched in between. These hidden layers can be few (in a shallow neural network) or numerous (in a deep neural network, DNN). One prominent subclass of ANN, especially prevalent in fields like medicine and dentistry, is the convolutional neural network (CNN).[5]

CNNs utilize a specialized architecture of neuron connections and employ convolution, a mathematical

operation, to analyse digital signals such as sound, images, and videos.

Brief History of AI

Artificial intelligence is not a novel concept. In his 1950 article "Computing Machinery and Intelligence," Alan Turing described the topic, anticipating a future in which machines are assumed to be capable of thinking. Despite the unavailability of the name "AI" at the time, Turing investigated the mathematical possibility of making intelligent machines and assessing their intelligence. He claimed that machines, like people, could approach problems and make decisions based on available data and reasoning.[6]

Subsequently, in 1955, John McCarthy, Marvin Minsky, Nathaniel Rochester, and Claude Shannon organized the Dartmouth Summer Research Project on Artificial Intelligence, marking the formal emergence of the term "AI." However, initial developments were primarily theoretical. It wasn't until the late 1950s to the mid-1970s that the AI field experienced rapid growth, propelled by advancements in computer technology, accessibility, and AI algorithms. Notable milestones during this period include ELIZA, a program capable of understanding spoken language and engaging in problem-solving through text-based interactions.[7]

Advancements in AI offer promising prospects for healthcare, including decreased postoperative risks, enhanced quality of life, more informed decision-making, and reduced unnecessary treatments. In the fields of medicine and dentistry, AI holds immense potential to enhance diagnostic precision and transform patient care. In dentistry specifically, AI is utilized for various purposes such as distinguishing between normal and abnormal structures, diagnosing disorders, and forecasting treatment results. Moreover, AI is extensively integrated into dental laboratories and is progressively shaping dental education methodologies.[8]

Artificial Intelligence and Dentistry

In recent years, artificial intelligence (AI) has grown significantly in dentistry. Its uses range from diagnostics to decision-making, therapy planning, and prediction of treatment outcomes. Among these, diagnosis is the most notable AI use in dentistry AI aids in achieving more precise and efficient diagnoses, thereby reducing the workload for dentists. As a result, there's a growing trend of dentists relying on computer algorithms for decision support. Simultaneously, computer programs tailored for dental purposes are becoming increasingly sophisticated, reliable, and accurate. Research in AI has extended across all domains of dentistry, showcasing its expanding influence.[9]

AI in Radiology

Convolutional Neural Networks (CNNs) have shown significant potential in identifying and naming anatomical features. For instance, some CNN models have been trained to recognize and label teeth in periapical radiographs. With precision rates ranging from 95.8% to 99.45%, these CNNs come close to matching the accuracy of clinical specialists, who achieve a precision rate of 99.98%. Deep CNNs hold promise for improving the sensitivity of diagnosing dental caries, and their efficiency, combined with speed, positions them as highly effective tools in this field.[10]

AI in Endodontics

Traditionally, dentists rely on visual, tactile, and radiographic examinations to diagnose dental caries based on specific criteria. However, detecting early-stage lesions can be challenging, especially in cases of profound fissures, tight interproximal contacts, and following lesions. Often, these lesions are only identified at advanced stages, leading to the need for more complex treatments like dental crowns, root canal therapy, or implants.[11]

Several studies in operative dentistry have looked into strategies for identifying dental caries, vertical root fractures, apical lesions, volumetric measurement of pulp space, and evaluating tooth wear. Two-dimensional (2D) radiographs provide grayscale images where each pixel's intensity corresponds to the object's density. AI programs can learn these patterns and make predictions to segment teeth, identify cavities, and more based on predefined criteria.

According to research, AI shows promising outcomes in early lesion diagnosis, with accuracy levels comparable to or higher than those of dentists.[12]

AI in Periodontics

AI plays a significant role in periodontics, particularly in diagnosis, treatment planning, and patient care. Leveraging machine learning and deep learning techniques, AI algorithms have shown impressive capabilities in diagnosing periodontal disease. By analysing clinical parameters like periodontal probing depths, attachment levels, and radiographic images, these models accurately identify and classify different disease stages, aiding in early intervention and personalized treatment planning. Additionally, AI-powered risk assessment tools help identify individuals at risk of periodontal diseases, enabling preventive measures and customized interventions.[13]

In treatment planning, AI algorithms support periodontists in devising optimal treatment strategies by considering patient-specific factors such as periodontal health, systemic conditions, and expected outcomes. These AI-driven decision support systems enhance treatment effectiveness, minimize risks, and improve long-term patient outcomes in periodontal therapy.[14]

AI in orthodontics

AI plays a crucial role in orthodontics, particularly in diagnosis, treatment planning, and improving treatment outcomes. Utilizing machine learning and deep learning techniques, AI algorithms have transformed orthodontic diagnosis by automating the analysis of various images and scans, such as cephalometric images, radiographs, dental impressions, and intraoral scans. These AI models provide precise evaluations of dental and skeletal irregularities, assisting orthodontists in accurate diagnosis and the creation of personalized treatment plans.[15]

Moreover, AI-powered software facilitates tasks like cephalometric analysis, dental arch measurements, and virtual tooth movement simulations, streamlining treatment planning and enhancing its predictability. In treatment delivery, AI-driven orthodontic systems, like clear aligner therapy platforms, utilize predictive analytics and biomechanical simulations to optimize outcomes and shorten treatment duration. By analysing patient-specific factors such as dental anatomy and occlusal relationships, orthodontists can tailor treatment protocols to individual needs, maximizing efficiency and patient satisfaction.[16]

Additionally, AI technologies enhance patient engagement and adherence to treatment through interactive monitoring apps, virtual consultations, and educational content. These tools empower patients, fostering collaboration with orthodontic providers and promoting positive treatment experiences.[17]

Furthermore, AI-driven research initiatives analyse large clinical datasets, identify biomarkers, and explore novel treatments, contributing to orthodontic knowledge and improving patient care. Continued research and collaboration are essential for fully realizing AI's potential in optimizing orthodontic outcomes and advancing global oral health.[18]

Artificial Intelligence in Pathology of the Mouth and Maxillofacial Regions

Early detection and diagnosis of oral diseases are crucial in dental practice since they significantly enhance patient prognosis. Given the risk that some oral lesions are precancerous or cancerous, accurate diagnosis and treatment are essential. Convolutional Neural Networks (CNN) have emerged as promising aids in this diagnostic process for head and neck cancer lesions. With specificity and accuracy rates ranging from 78% to 81.8% and 80% to 83.3%, respectively, CNNs exhibit significant potential for detecting tumoral tissues in tissue samples or radiographs, though slightly lower compared to specialists whose rates were 83.2% and 82.9%, respectively.

In one study, a CNN algorithm successfully distinguished between two maxillary tumors, ameloblastomas, and keratocystic odontogenic tumors, despite their similar radiologic appearances but distinct clinical properties. The CNN achieved a specificity of 81.8% and an accuracy of 83.3%, comparable to clinical specialists at 81.1% and 83.2%, respectively. Notably, the CNN achieved these results in a significantly shorter diagnostic time, with an average of 38 seconds, compared to specialists who took 23.1 minutes on average to reach a diagnosis.[19]

AI in Prosthodontics

The usual technique for constructing a dental crown in prosthodontics consists of multiple steps, including tooth preparation, impression taking, cast trimming, restoration design, manufacturing, try-in, and cementation. The primary application of AI in prosthodontics lies in restorative design, particularly

through CAD/CAM systems like CEREC, Sirona, and 3 Shape, which have streamlined design processes. Although using a tooth library to create crowns has improved design efficiency, it falls short of providing entirely individualized designs for each patient. In prosthodontic practices, integrating AI with CAD/CAM or 3D/4D printing may increase workflow and production.[20]

Furthermore, AI has been employed to predict shade matching and debonding issues with CAD/CAM restorations. However, in the realm of removable prosthodontics, design poses more challenges due to additional variables. Despite the availability of various expert systems, there isn't currently a machine learning algorithm specifically tailored for creating removable dentures. Instead, current machine learning approaches mainly focus on aiding in aspects like dental arch categorization and predicting facial appearance in edentulous individuals to assist with removable denture design.[21]

AI applications in Dentistry
Summary

Table 1: Application Artificial intelligence in different branches of dentistry.

AI applications in Dentistry	Types of Applications	References
Oral Radiology	-Identify and label teeth from periapical radiographs. -To detect Carious Lesions	Zhang K *et al* (2018)[22]
Endodontics	- Vertical root fracture detection - Apical lesion detection - Tooth wear evaluation - Dental caries detection	Fukuda M, Inamoto K *et al* (2020)[23]
Periodontics	- Periodontal bone loss detection - Severity of chronic periodontitis prediction - Periodontal condition examination	Kim E-H *et al* (2020)[24]
Orthodontics	- Orthodontic treatment results prediction - Tooth extraction determination in orthodontic treatments - Cephalometric landmarks locating - Skeletal classification	Jung S-K *et al* (2016)[25]
Oral and maxillofacial surgery	- Mandibular third molar and IAN positional relationship detection - OPMDs and OSCC diagnosis - Ameloblastoma and KCOT diagnosis	Warin K *et al* (2022)[26]
Prosthodontics	- Crown generation - Shade matching - Resin composite crowns debonding prediction - Dental arch classification	Takahashi T *et al* (2021)[27]

Discussion

AI's evolution has demonstrated its ability to transcend human understanding, a feat that is heavily reliant on advances in computer technology (software), processing power (hardware), and massive databases (input data). Training algorithms for machine learning (ML) problems utilizing 3D models requires significant computer resources. However, current computer capabilities may not suffice for executing classification or regression tasks directly on 3D data compared to well-explored 2D image and video applications.[28]

To mitigate processing demands, various sampling and representation methods (e.g., depth maps, voxels, point clouds, and meshes) are often

employed, albeit at the expense of sacrificing some features during transition. The emergence of wearable devices and the digitization of medical data, previously unavailable for ML model training, significantly contribute to the collection of medical big data. Consequently, the advancement of AI applications heavily relies on refined AI algorithms, enhanced computer capabilities, and the availability of digitized training data.[29]

Utilizing dental and medical data for machine learning training requires utmost caution due to its complexity, sensitivity, and limited validation methods. Data from computerized records in healthcare settings often exhibits low quality, lacking systematic allocation and randomness. For instance, hospital data may skew towards more severe cases, while data from wearable devices may lean towards healthier individuals. Moreover, disparities in healthcare systems across countries and regions further complicate data reliability and consistency.[30]

Challenges of AI

The utilization of AI systems in healthcare encounters several challenges in terms of managing and distributing clinical data. Patient information is essential for training and continuously improving AI algorithms, necessitating measures to safeguard confidentiality and privacy, especially with potential cross-border data exchange. Anonymizing personal data becomes imperative before broader distribution of AI systems in healthcare operations.[31]

Safety concerns regarding AI systems also need to be addressed. Ensuring the quality and reliability of AI algorithms is crucial, prompting regulatory measures such as the creation of a new medicine category called "Software as Medical Device" by the United States Food and Drug Administration to oversee safe innovation and patient safety.

Furthermore, transparency in AI algorithms and data is essential. The accuracy of annotations and labels in training datasets has a major impact on the quality of predictions generated by AI systems, emphasising the need of high-quality data labelling. Healthcare providers must also understand and be able to justify the decisions and predictions made by AI systems, which may require improvements in the interpretability of AI technology, especially for complex algorithms like neural networks, before they can reliably offer clinical diagnosis or treatment suggestions.[32]

Conclusion

In dentistry, there's a rapid emergence and adoption of new technologies, among which AI stands out as highly promising. AI provides outstanding accuracy and efficiency, especially when combined with unbiased training data and a finely tuned algorithm. Dental professionals can harness AI to alleviate their workload while simultaneously enhancing precision and accuracy across various aspects such as diagnosis, decision-making, treatment planning, prediction of treatment outcomes, and prognosis of illnesses.

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Conflict of Interest

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Data Availability Statement

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