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ROLE OF ARTIFICIAL INTELLIGENCE (AI) IN MODERN DENTISTRY: A NARRATIVE REVIEW

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Abstract

Artificial Intelligence (AI) refers to the capability of machines to perform tasks that traditionally require human intelligence, such as learning, problem-solving, and decision-making. Within AI, machine learning (ML) and its subdomain, deep learning, have enabled systems to process vast amounts of data, identify patterns, and improve their performance over time. ML can be categorized into supervised, unsupervised, and semi-supervised learning, each with specific applications in healthcare. In recent years, AI has made remarkable progress in the medical field, including dentistry. Its integration into dental practice has led to significant improvements in diagnosis, treatment planning, and patient care. AI technologies have shown great promise in the early detection of dental caries, periodontal disease, and oral cancers, thereby reducing morbidity and mortality. Additionally, AI has enhanced the precision and efficiency of procedures in orthodontics, oral and maxillofacial surgery, and operative dentistry. Despite these advancements, the widespread use of AI in dentistry raises important ethical and legal concerns. Key issues include patient data privacy, accountability in the event of misdiagnosis or harm, algorithmic bias, and the potential for technical errors. While AI offers benefits such as faster and more accurate diagnostics, reduced clinician workload, and improved access to care in underserved regions, it cannot fully replace human judgment and empathy. Instead, a collaborative approach, combining AI capabilities with clinical expertise, holds the greatest promise for the future of dentistry.

INTRODUCTION

Artificial intelligence represents a paradigm shift in technology, focused on the creation of systems and algorithms possessing the capability to perform tasks that conventionally require human cognitive abilities. These tasks extend from foundational pattern interpretation to complex evaluative reasoning.[1] AI systems are formulated to not just derive insights from data but also to react dynamically to novel information, thereby continuously refining their operational accuracy. As technology continues to exhibit an unprecedented innovation and improvement, AI has established itself as the most pivotal revolution, effortlessly embedding itself into various domains of daily life and industry by leveraging enormous quantities of data produced by electronic devices[2]

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that's why it is considered a disruptive technology which is swiftly infiltrating diverse sectors and domains, encompassing healthcare, business, industrial sector, educational sector, agricultural sector and urban development sector[3]. AI is becoming increasingly indispensable, catalyzing a shift in Diagnostics, new drug development, personalized therapeutic approach, data evaluation and operational efficiency. These intelligent systems assist healthcare professionals by mitigating the operational strains and refining diagnostic precision.[4] In contrast to the customary approaches the usually draws upon conventional unimodal data, AI can integrate and evaluate multi-modal datasets thereby merging diagnostic images with social and demographic parameters in order to make conduct predictive analysis that transcend human competencies and skills.[5] The breakneck advancement of AI is catalyzed by scientific development in computing power, sophisticated algorithms, and the availability of extensive datasets. This harmonization formulates profound prospective avenues for AI integration in medicine and dentistry, predominantly for disease diagnosis, predictive outcome estimation, designing effective treatment interventions and patient health monitoring.[6] specifically in dental practice, AI-enabled technologies are optimizing reliability of diagnostic assessment, paving way for the proactive recognition of dental decay, and maximizing the effectiveness of patient centered care approach.[7] AI-driven tools are enhancing diagnostic accuracy, enabling early detection of oral diseases, and optimizing personalized care.[2]

HISTORY OF ARTIFICIAL INTELLIGENCE:

The conceptual foundations of artificial intelligence began with Aristotle (384–322 B.C.), whose development of syllogisms laid the groundwork for deductive reasoning (Smith, 2020). Blaise Pascal in 1642 invented a device "pascaline" to perform subtraction and addition. In 1694, Leibniz innovated a machine "Leibniz wheel" for multiplication and division, he also anticipated contemporary concepts of inference and proof automation in 1887.[8]The pioneering program in Artificial intelligence was logic theorist(1956) written by Allen Newell, Herbert A. Simon, and Cliff Shaw which was able to prove 38 out of 52 theorems of "Principia Mathematica" [9]

-Back in the time when no term was coined for Artificial Intelligence a British mathematician Turing posed a question: "Can machines think? In his renowned publication "Computing Machinery and Intelligence". He brought forth a method known as "Turing test" where he evaluated whether a machine was able to exhibit intelligence indistinguishable from human intelligence or not. [2] The term AI was first used in 1955 by John McCarthy, who is known as the father of artificial intelligence. The Dartmouth conference which was held in 1956 which served as the foundational moment in the history of AI. It was after this conference that artificial intelligence entered a new era wherein wide ranging research on AI started.[10]In 1972, Feigenbaum, Buchanan, and Dr. Edward Shortliffe developed a program called MYCIN that was capable of diagnosing blood infections using 450 rules.[11]

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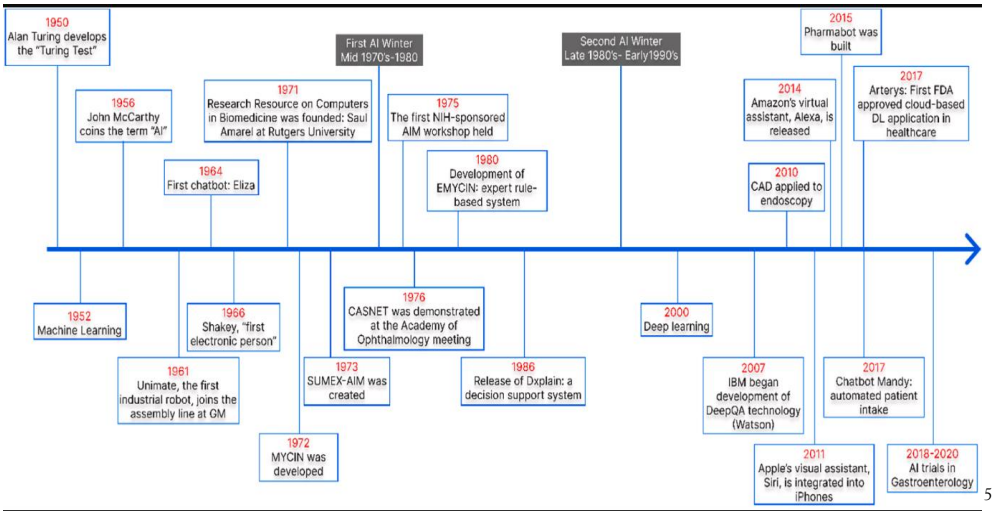

[5]

CLASSSIFICATION OF ARTIFICIAL INTELLIGANCE:

Artificial Intelligence, on the basis of capability has been divided into two main broad domains: Strong AI and weak AI. These domains are further divided into Artificial Narrow Intelligence (ANI), Artificial General Intelligence (AGI) and Artificial Superintelligence (ASI).[5, 12]

Artificial Narrow Intelligence, also known as Weak AI, refers to the systems that are built to carry out specific tasks within a limited scope. These systems operate based on pre-set rules and training data, and they do not possess consciousness or true understanding.[2, 13]

The artificial intelligence system possessing intelligence equal to that of human intelligence is referred to as Strong Artificial Intelligence.[2, 14]

Machine learning is the subfield of Artificial Narrow Intelligence.[2] Machine learning is the science of designing algorithms that learn patterns from data to automatically make predictions or decisions, generalizing to new, unseen instances without explicit programming.[15, 16]The term Machine learning was coined by Simon Cowell in 1959.[17]

Machine learning is further divided into three subgroups: supervised learning, unsupervised learning and semi supervised learning

SUPERVISED LEARNING involves training algorithms using datasets that include input-output pairs, where the correct output, the *ground truth*, is already known. The model learns to map inputs to the corresponding outputs, enabling it to make accurate predictions on new, unseen data.[18-20]

UNSUPERVISED LEARNING operates on data that has no pre-assigned labels. The algorithm's objective is to uncover hidden patterns, relationships, or structures within the data without external guidance.[18-20]

SEMI SUPERVISED LEARNING uses both labelled and unlabelled data during training.[2]

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Items	Supervised learning	Semi-supervised learning	Unsupervised learning
Input type	Labelled data	A mixture of labelled and unlabelled data	Unlabelled data
Accuracy	High	Mid	Low
Complexity of the algorithm	Low	Mid	High
Types of algorithm	Regression and classification	Regression, classification, clustering, and association	Clustering and association

[2]

Artificial Neural Networks a subfield utilizes artificial neuron that recaive and analyze data thereby mimicing human brain. [21] In 1943, Warren McCulloch and Walter Pitts suggested using neural networks to mimic how the human brain works. [22]

Deep learning is a subfield of Machine Learning [2] which uses multi-layer neural networks to analyze and compute data.[16]This approach was introduced by Hinton et al. in 2006.[21,23] Deep Learning (DL) uses models made up of several layers to automatically learn features from data at different levels of detail. Because of this, DL can understand complex patterns more effectively and is less affected by differences in how humans interpret the data. This makes DL a more powerful alternative to traditional machine learning techniques.[20]

AI IN DENTISTRY:

Artificial intelligence has come forth as a prominent force in modern health care, reshaping diagnostic assessment and medical processes across several medical domains, including dentistry.[7] Artificial intelligence (AI) is helping improve how dental care is delivered by making data analysis faster and more accurate. It can quickly process large amounts of information such as X-rays, clinical notes, and patient histories to support better treatment decisions. This leads to more personalized, efficient, and reliable care. In dentistry, AI is changing the way professionals diagnose and treat patients, making the process more precise and patient-focused.[24] Human error in early disease detection can lead to misdiagnosis or delayed diagnosis, often resulting in more complex treatments, longer consultation times, and increased patient burden. Subtle signs of dental conditions may be overlooked due to fatigue, inexperience, or time constraints. However, the integration of artificial intelligence (AI) in dentistry helps reduce these challenges by offering accurate, consistent, and rapid analysis of clinical data. As a result, AI supports dentists in making more reliable diagnoses, minimizes the risk of oversight, and enables faster, more efficient treatment planning. [25,26]Dental caries detection is one of the most extensively studied areas where AI has demonstrated considerable promise. Beyond caries, AI technologies have been integrated into oral radiology, offering enhanced analysis of panoramic and cone-beam computed tomography (CBCT) images.[27]As AI technologies continue to mature and integrate into clinical workflows, they hold the potential to revolutionize dental practice and improve oral health outcomes on a global scale.

ROLE OF AI IN OPERATIVE DENTISTRY:

Dental caries affects over 3.4 billion people globally and is often challenging to detect early,

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even with radiographs, due to variability in human interpretation. Early detection is crucial to avoid invasive treatments and reduce costs. [21]Artificial intelligence, particularly machine learning models, offers a highly accurate and consistent approach to caries detection and can also predict disease progression.

Zadrożny et al. assessed the performance of an AI system (Diagnocat) in analyzing panoramic radiographs. The AI showed high specificity (>0.9) for most findings but had lower reliability in detecting caries and periapical lesions. The study concluded that AI can assist in initial screening but should be supplemented by expert review.[28]

Lian L. employed deep learning techniques to detect and classify dental caries using panoramic radiographs. They utilized nnU-Net for lesion segmentation and DenseNet121 for classifying caries depth into D1, D2, and D3 categories. The models demonstrated performance metrics comparable to those of expert dentists, suggesting that deep learning methods can effectively assist in caries diagnosis and treatment planning.[29]

The third most common cause of tooth loss are cracked teeth. [30]Shah et al. developed an automated framework for detecting and measuring cracks in teeth using high-resolution CBCT imaging. The method combines steerable wavelet analysis with support vector machine (SVM) classification. It accurately distinguishes cracked teeth from healthy ones with high sensitivity and specificity. This approach shows strong potential for early, non-invasive dental crack diagnosis.[31]

ROLE OD AI IN ORAL AND MAXILLOFACIAL SURGERY:

In oral and maxillofacial surgery, AI-driven robotic systems replicate human dexterity and decision-making, significantly enhancing surgical precision. Image-guided techniques have improved the success of procedures such as tumor removal, biopsies, and dental implant placements. Compared to traditional methods, AI-assisted surgeries offer shorter operation times, greater accuracy, and safer handling of delicate anatomical structures, leading to better patient outcomes[32].

Yang and Su (2021) introduced an AI-based system for automatic segmentation of skull CT scans to support craniomaxillofacial surgery. The model achieved high accuracy, meeting clinical requirements for surgical planning. The study highlights AI's potential to improve both preoperative and postoperative workflows.[33]

Zhang W. developed a predictive model using artificial neural networks (ANNs) to forecast facial swelling after impacted mandibular third molar extraction. The model was trained on clinical and anatomical data. It showed high accuracy in predicting postoperative swelling. Thus demonstrating the usefulness of supervised AI in enhancing surgical outcome predictions.[34]

Chiesa-Estomba et al. (2021) applied machine learning models to predict facial nerve palsy after parotid gland surgery for benign tumors. Using clinical, radiological, histological, and cytological data from 736 patients, the study achieved high accuracy, especially with ANN and KNN models. The results showed that AI can serve as a reliable preoperative assessment tool. This allows surgeons and patients to better understand and prepare for potential complications.[35]

ROLE OF AI IN DIAGNOSING ORAL CANCER:

Oral cancer is characterized by one of the poorest cancer survival rates worldwide. Oral Cancer is often diagnosed in advanced stages worsening health outcomes, aggravating the rate of mortality and morbidity and amplifying the risk of recurrence. Moreover, it increases the cost of treatment and patient anxiety.[36]Oral cancer accounts for approximately 2% of all newly diagnosed cancer cases worldwide. Around 90% of these are squamous cell carcinomas that originate from the oral epithelium. The remaining 10% include a range of less common malignancies, such as intraoral salivary gland tumors, melanomas, soft tissue and jawbone sarcomas, non-Hodgkin's lymphomas, as well as rare malignant odontogenic tumors and metastatic cancers that have spread from other parts of the body.[37]

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Morikawa T. determined the accuracy of fluorescence visualization, a non-invasive, convenient, and repeatable technique using optical instruments. He compared subjective clinical evaluation with objective image analysis metrics and found that subjective evaluation showed high sensitivity but had low specifity. On the other hand, objective evaluation had high specifity and sensitivity. Thus combining both methods support accurate, non-invasive and repeatable oral cancer screening especially in low resource settings. [38]

Song B et al. developed a low-cost, smartphone-based dual-modality imaging system that captures both auto fluorescence and white-light intraoral images. They applied deep learning methods, including convolutional neural networks with transfer learning and image fusion techniques—to automatically classify dysplasia and malignancy in oral lesions. The system demonstrated strong performance, showing that deep learning can effectively process and fuse dual-modal images for accurate oral cancer detection in low-resource settings.[39]

Rahman et al. developed a portable, battery-powered imaging system for detecting oral cancer in remote, low-resource areas. The device captures real-time reflectance and fluorescence images of oral tissue. It demonstrated high sensitivity and specificity in distinguishing cancerous from non-cancerous areas, showing promise for affordable cancer screening.[40]

Warin K developed novel deep convolutional neural networks (CNNs) to analyze oral lesion images for the early detection of oral cancer. Their AI models demonstrated high accuracy and sensitivity in distinguishing malignant from benign lesions. The study highlights the potential of deep learning to improve early diagnosis and support clinical decision-making in oral oncology.[41]

ROLE OF AI IN PERIODONTICS:

AI enhances diagnostic accuracy by analyzing dental radiographs to detect early signs of periodontal disease. It also aids in personalized treatment planning by integrating patient data, medical history, and risk factors. Additionally, AI can predict disease progression, allowing for proactive interventions.[42]

Xinyu et al. conducted a randomized clinical trial to assess the impact of an AI-enabled multimodal-sensing toothbrush combined with targeted mobile Health micro messages on periodontitis management. The intervention group showed significantly greater reductions in periodontal inflammation and improved oral hygiene compared to standard care. Enhanced patient adherence and better clinical outcomes were observed with the AI-supported approach. This study highlights the potential of AI-driven technologies to improve personalized periodontal care and treatment effectiveness.[43]

In a retrospective study, Ossowska A. explored the use of artificial neural networks (ANNs) to predict the progression of periodontitis. The model was trained using a range of clinical and demographic parameters, including age, sex, smoking status, plaque index, bleeding on probing, probing depth, and clinical attachment loss, following the 2017 periodontitis classification system. The ANN achieved an accuracy of 84.2%, with a sensitivity of 85.7% and specificity of 80.0%. These findings highlight the potential of AI-driven models to support early detection and risk-based classification in periodontal care, helping clinicians make more informed treatment decisions.[44]

Ameli et al. developed a BERT-based natural language processing model to classify the stage and grade of periodontitis using unstructured clinical notes. The model achieved 77% accuracy for staging and 75% for grading, performing significantly better than traditional machine learning approaches. It also maintained strong results on unseen data, suggesting its usefulness in real-world dental settings for improving diagnostic efficiency.[45]

Krois et al. (2019) used deep learning to detect periodontal bone loss from dental radiographs. Their AI model achieved accuracy comparable to experienced dentists, highlighting its potential as a supportive diagnostic tool in periodontal care.[46]

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ROLE OF AI IN PROSTHODONTICS:

Prosthodontics is the field of dental prosthesis which combines art and a science. With the advancement of Artificial Intelligence in dentistry, prosthodontics has also witnessed advancement, improving everything from material used to diagnosis, treatment plan and prosthesis fabrication.[47]

Gerhardt et al. (2022) developed a CNN-based system for automatic detection and labeling of teeth and small edentulous regions in CBCT scans. The model achieved over 99% accuracy and completed tasks in a median time of 1.5 seconds, compared to 98 seconds taken by human experts. This demonstrates the model's potential to greatly enhance speed and efficiency in dental diagnostics.[48]

Hasan et al. (2021) developed an intelligent model named Dental Impression Tray Selection Network (DITS-Net) to automate the selection of dental impression trays based on maxillary arch images. By applying multi-feature fusion (color, shape, and texture) and an ensemble classifier, the system achieved an accuracy of 91.75%. The model demonstrated strong potential for improving efficiency and accuracy in prosthodontic procedures.[49]

ROLE OF AI IN ORTHODONTICS:

Orthodontic diagnosis is a complex, multidisciplinary process that encompasses facial analysis, occlusal evaluation, and consideration of individual patient needs. Due to its detailed and time-intensive nature, integrating artificial intelligence can significantly enhance both diagnostic accuracy and efficiency in treatment planning.[50]

Choi and Lee (2021) examined the potential of AI in orthodontics, particularly in image recognition and 3D visual treatment objectives (VTO). They concluded that AI can enhance cephalometric analysis and automate VTO generation, aiding in complex treatment decisions like extractions and orthognathic surgery.[51]

The use of radiography, intraoral scanners, and 3D imaging has revolutionized orthodontic diagnosis and treatment planning, reducing reliance on traditional impression-taking and improving accuracy. AI-driven algorithms now assist in predicting tooth movement and treatment outcomes. AI is actively applied throughout orthodontic care, from diagnosis to monitoring, with 3D scans enabling precise evaluation and the creation of customized aligners for faster, more accurate treatment.[52]

Tanikawa et al. developed two AI-based systems to predict post-treatment facial morphology in Japanese patients: one for orthognathic surgery (System S) and another for orthodontic treatment with premolar extraction (System E). Both systems combined geometric morphometric landmark analysis with deep learning to model 3D facial changes. System S achieved an average prediction error of 0.94 mm, correctly predicting facial changes within 1 mm in 54% of cases. System E performed more accurately, with a 0.69 mm average error and 98% of predictions falling within 1 mm. Both models achieved 100% accuracy within a 2 mm tolerance, demonstrating clinically acceptable and highly reliable results. This study highlights the potential of AI to enhance facial outcome prediction in orthodontic and surgical planning.[53]

ETHICAL CONSIDERATIONS IN THE USE ARTIFICIAL INTELLIGENCE:

With its tremendous potential to strengthen healthcare domains, it also entails several ethical challenges that cannot be overlooked. For responsible use of AI four major issues need to be addressed: protecting patient privacy, getting clear consent for data use, ensuring systems are safe and transparent, and preventing bias in algorithms.[47]Another concern is that the use of AI in healthcare raises serious ethical concerns about accountability when things go wrong. Unlike doctors, AI systems lack a clear structure for assigning blame in cases of error or harm. This gap threatens both patient safety and the legal foundation of responsibility in medicine[54].AI in healthcare relies on massive amounts of patient data, but this raises serious ethical concerns. Patients may not know their information is being used, who's using it, or if it's been fully anonymized. There's also the risk

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that their data could be used for profit or become vulnerable to future legal changes. To ensure responsible use, healthcare AI must follow key ethical principles like informed consent, privacy, transparency, fairness, and clear rules about who owns the data.[55]

CONCLUSION:

Artificial intelligence is rapidly transforming the field of dentistry by improving diagnostic accuracy, personalizing treatments, and streamlining clinical workflows. From early detection of oral diseases to enhancing specialties like orthodontics and oral surgery, AI offers promising advancements that can improve patient outcomes and access to care. However, its integration into dental practice also brings challenges, including data privacy concerns, accountability issues, and the risk of errors or bias. Addressing these concerns through ethical guidelines, transparent algorithms, and collaboration between dental professionals and technology experts is essential. While AI cannot replace human expertise and judgment, it can serve as a powerful tool to support and enhance clinical decision-making. Together, AI and human intelligence can lead to safer, more efficient, and patient-centered dental care.

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