ARTIFICIAL INTELLIGENCE IN DENTISTRY – CURRENT APPLICATIONS AND FUTURE PROSPECTS

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ABSTRACT

Artificial Intelligence (AI), named in 1956 by John McCarthy, spans various fields such as visual perception and computer linguistics. Recent advances suggest the AI healthcare market will grow from $1.3 billion to $10 billion by 2024, driven by a 40% annual growth rate.

AI includes symbolic AI and machine learning (ML). Symbolic AI uses human-readable algorithms and was prominent until the 1980s. ML, coined by Arthur Samuel in 1952, uses statistical methods to learn from data rather than predefined rules.

In dentistry, AI's use has been limited but is growing, with early applications in automated caries detection and ongoing use of cephalometric X-rays for orthodontics. AI's potential in orthodontics includes improving diagnosis, treatment planning, and outcome prediction, which could enhance treatment effectiveness and patient satisfaction.

AI types include Purely Reactive, Limited Memory, Theory of Mind, and Self-Aware. Machine learning (ML) models learn from data rather than predefined rules, with deep learning using neural networks for feature extraction. In orthodontics, AI enhances diagnosis and prognosis through techniques like convolutional neural networks (CNNs) for medical imaging and data-driven decision-making.

Machine learning has significantly advanced in areas like speech recognition and data analysis, transforming industries by optimizing models through training and testing. Deep learning, an advanced technique, builds on artificial neural networks inspired by biological systems.

AI in dentistry has made significant strides across various specialties. In operative dentistry, AI enhances cavity detection and caries diagnosis through convolutional neural networks (CNNs), proving more efficient and cost-effective than traditional methods. Oral pathology benefits from AI in detecting cancers and lesions via imaging techniques, improving diagnostic accuracy. In

prosthodontics, AI supports personalized crown design and color matching, streamlining workflows. Orthodontics leverages AI for diagnosis and treatment planning but faces challenges with facial aesthetics and functional issues. AI also improves cephalometric analysis, skeletal age determination, and decision support for orthognathic surgery, though further refinement is needed.

INTRODUCTION

Artificial Intelligence (AI) emerged as a field of study shortly after World War II, with the term "AI" being coined in 1956 by John McCarthy at Dartmouth College.(1)

AI encompasses a wide range of applications, including knowledge-based systems, visual perception, gaming, computer linguistics, and mechatronics.(2) Recent progress in informatics has enabled AI algorithms to tackle complex tasks, particularly in healthcare. As per a 2019 projection by Morgan Stanley, the worldwide AI market in healthcare is anticipated to witness a notable increase from $1.3 billion to $10 billion by 2024, showcasing an annual compound growth rate of 40%.

AI can be broadly classified into two main categories: symbolic AI and machine learning, from an algorithmic standpoint.

Symbolic AI relies on structuring algorithms in a human-readable symbolic manner and was the dominant paradigm until the late 1980s, often referred to as GOFAI (good old-fashioned AI).(3)

Arthur Samuel coined the term "machine learning" (ML) in 1952, which now epitomizes the prevailing paradigm. Machine learning (ML) utilizes mathematical and statistical methodologies, empowering machines to enhance their abilities through self-adapting algorithms. (4)

The key difference between ML and symbolic AI lies in their approach to learning:
ML learns from examples rather than predefined rules set by humans.(5)

Despite AI's widespread integration into human medicine, its application in dentistry has been limited until recently. It has now been introduced into dental education, research and even in diagnosis.

Orthodontic treatment focuses on modifying occlusion and controlling dentoalveolar components and growth abnormalities. Accurate assessment of these issues is essential for determining treatment needs and priorities.(6) Prior to treatment, orthodontists must provide patients with comprehensive information, including treatment plan alternatives, duration, costs, expected success rates and potential risks. Utilizing computerized intelligent models could enhance this process by suggesting optimal treatment protocols and predicting treatment outcomes.

AI offers significant potential in orthodontics by aiding in diagnosis, treatment planning, and outcome prediction. Its integration into orthodontic practice has the potential to improve treatment efficacy and patient satisfaction. (7)

HISTORY –

Can Machines Think?

During the 1950s, a British polymath, who explored the mathematical possibilities of AI suggested that humans use available information and logic to tackle problems and make decisions, leading to the inquiry: why couldn't machines do likewise? This served as the foundational premise of his influential 1950 paper, "Computing Machinery and Intelligence," where he explored the development of intelligent machines and methods for assessing their intelligence. [8]

Prior to 1949, computers lacked a critical requirement for intelligence: the ability to store commands, rather than just execute them.

The Conference that Started it All

During the conference, The Logic Theorist, funded by the Research and Development (RAND) Corporation, to emulate human skills, it was showcased at the Dartmouth Summer Research Project on Artificial Intelligence (DSRPAI) organized by John McCarthy and Marvin Minsky in 1956. McCarthy brought together prominent researchers from various disciplines for an extensive exploration of artificial intelligence, a term he coined during the event. This gathering has ignited two decades of subsequent AI research. [9]

Success and Setbacks

From 1957 to 1974, the AI field underwent a period of expansion where computers notably progressed in terms of storage capacity, speed, cost-effectiveness, and availability.

During the 1980s, AI saw a revival propelled by progress in algorithms and augmented funding. John Hopfield and David Rumelhart gained prominence for popularizing "deep learning" methods, empowering computers to acquire knowledge through experience.

In the 1990s and 2000s, IBM's Deep Blue made history by defeating the reigning world chess champion Gary Kasparov in 1997, representing the inaugural instance of a computer prevailing over a human at such a high level of chess competition.

Types of Artificial Intelligence

- Purely Reactive
- Limited Memory
- Theory of Mind
- Self-Aware

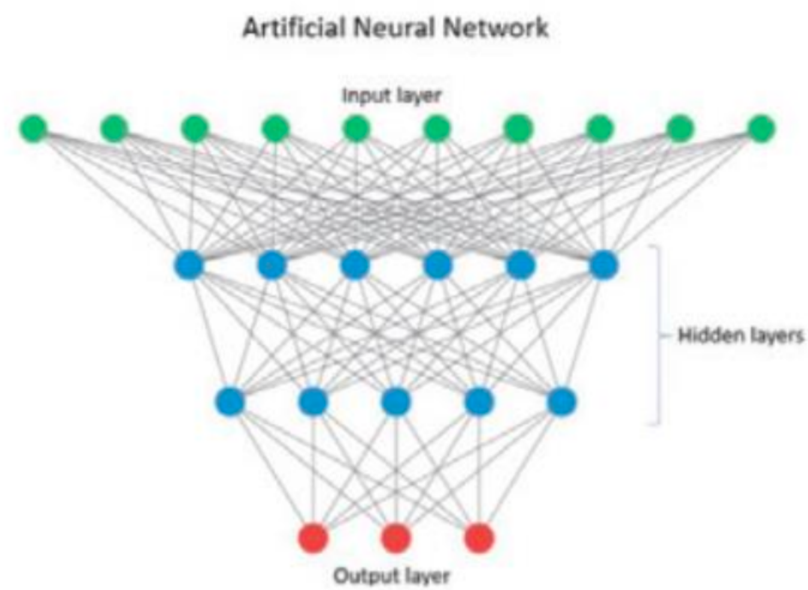
In machine learning (ML), models acquire knowledge from examples rather than predefined human rules, leveraging statistical and probabilistic techniques to enhance actions based on fresh data. Deep learning, a subset of ML, involves the calculation of specific input features by the machine itself, with artificial neural networks serving as its precursor.

AI applications in orthodontics leverage various algorithms and techniques to enhance diagnostic accuracy and treatment prognosis prediction.[10,11]

Convolutional neural networks (CNNs) are increasingly utilized for medical image diagnostics, particularly for detecting, segmenting, or classifying anatomical structures, while machine learning approaches enable data-driven decision-making in orthodontics. (12)

MACHINE LEARNING –

Machine learning has undergone remarkable advancement over the last two decades, in fields such as speech recognition, natural language processing, and robot control. (13)
The impact of machine learning extends across computer science and industries dealing with data-intensive challenges, including consumer services. These methods have revolutionized the analysis of high-throughput experimental data.
Machine learning typically involves a training process, where a model or set of functions is evaluated and optimized using training data and algorithms, followed by a testing process to evaluate the chosen function's performance with testing data. Deep learning, an advanced technique in machine learning, derives its foundation from artificial neural networks (ANNs), which draw inspiration from biological neural networks governing learning and perception. (14)



Artificial Neural Network Structure

TYPES OF MACHINE LEARNING ALGORITHMS

- SUPERVISED LEARNING
- UNSUPERVISED LEARNING
- REINFORCEMENT LEARNING
- RECOMMENDER SYSTEMS

In dentistry, AI-driven tasks revolve around classification, regression, detection, and segmentation. Classification involves assigning objects or features to predefined categories, with

convolutional neural networks (CNNs) excelling in handling high-dimensional data like high-resolution images.[15]
Overall, machine learning continues to revolutionize various fields with its ability to develop intelligent systems, and its significance is expected to persist and grow in the future. [16]

ARTIFICIAL NEURAL NETWORK

Artificial Neural Networks (ANNs) are computational models inspired by the biological neural networks found in the human brain. They consist of interconnected nodes, or neurons, that process information in a parallel manner. These networks are widely used in various fields related to information processing, such as pattern recognition, forecasting, and data compression.
Each artificial neuron in an ANN receives inputs, which are then multiplied by weights to represent the information flow.
ANNs are particularly beneficial in medical research for tackling complex and uncertain problems, including prognostication, classification, pattern recognition, and image processing.[17]

ARTIFICIAL INTELLIGENCE IN DENTISTRY

AI IN OPERATIVE DENTISTRY

In conservative dentistry, research has focused on various aspects such as detecting cavities, root fractures, periapical lesions, and evaluating attrition. AI algorithms can leverage these characteristics to learn patterns and make predictions, such as segmenting the tooth or detecting caries.
Lee et al. devised a convolutional neural network algorithm to identify decay on X-rays, whereas Kühnisch et al. introduced a CNN algorithm for detecting decay in intraoral images.
Schwendicke et al. conducted a study that compared the economic efficiency of AI-driven inter-proximal caries detection with diagnoses made by clinicians, demonstrating that AI was both more effective and less expensive.
Numerous studies have demonstrated the promising results of AI in early lesion detection, often achieving accuracy equal to or better than that of dentists. This necessitates interprofessional collaboration between data scientists and healthcare providers. [18]

AI IN PERIODONTICS

Artificial intelligence has been employed to diagnose and identify different types of pathologies. For instance, Krois et al. applied convolutional neural networks (CNN) to detect bone loss on radiographs. Lee et al. employed a CNN algorithm specifically crafted to automatically identify affected teeth.
Additionally, Yauney et al. suggested that periodontal pathologies can be evaluated using a CNN algorithm, utilizing general health-related data.

AI IN ORAL PATHOLOGY

Oral Pathology involves the diagnosis of diseases affecting the entire head and neck area, including oral cancer, a major concern globally. AI research in OMFP focuses on automating tumor and cancer detection using various imaging techniques like radiography and microscopy. CNN algorithms show promise in this area. [19]

Early detection of mucosal lesions is crucial for distinguishing between benign and malignant conditions. Pathologists currently rely on labor-intensive methods, but AI could aid in this process by analysing biopsy slides and radiographs. For instance, AI algorithms are used to differentiate between non-cancerous and cancerous lesions in the oral mucosa using optical coherence tomography.

These AI tools offer accuracy comparable to that of oral and maxillofacial specialists, indicating their usefulness in improving diagnosis and treatment planning. [20]

AI IN PROSTHODONTICS

The dental crown preparation procedure encompasses several stages and CAD/CAM technology has streamlined this process by digitizing design work, but customized designs for individual patients remain a challenge. Recent advancements in AI offer promising solutions. Hwang et al. and Tian et al. introduced novel methods employing 2D-GAN models to create personalized crowns by analysing designs from technicians. Incorporating AI into CAD/CAM or 3D/4D printing systems greatly improves the efficiency of workflow.

Additionally, AI has been utilized in colour matching and forecasting the debonding of CAD/CAM restorations.

As AI continues to evolve, it holds promise for enhancing precision and efficiency in dental practice. Dentists can leverage AI as a valuable tool to streamline workflows and improve diagnostic accuracy and treatment outcomes. [21]

ARTIFICIAL INTELLIGENCE IN ORTHODONTICS

Orthodontics represents the specialized realm within dentistry dedicated to rectifying dental and craniofacial anomalies through meticulous diagnosis, strategic intervention, and tailored treatment modalities. Through the adept deployment of orthodontic appliances ranging from traditional braces to cutting-edge clear aligner systems, they endeavor to restore both functional integrity and aesthetic equilibrium to the oral cavity, thereby bestowing upon their patients the dual benefits of enhanced oral health and an impeccably radiant smile. [22]

One current limitation of AI algorithms in orthodontics is their lack of integration with patients' facial analysis, proportions, and esthetics. Orthodontic tooth movements are intricately linked with facial esthetics, and only qualified orthodontists can effectively analyze these factors. Facial analysis is crucial for identifying dentofacial deformities and determining the potential need for surgical orthodontic corrections.[23]

Additionally, existing AI systems do not adequately account for functional issues and the stability of tooth positions following orthodontic treatment. For instance, aligners may be used to treat conditions like open bite malocclusion, but current AI models struggle to identify the underlying causes of such problems or predict appropriate retention strategies.

In machine learning, algorithms must be trained on benchmark data, typically derived from successful treatment outcomes.

In summary, while AI holds promise for advancing orthodontic treatment, significant improvements are needed to address these limitations and ensure algorithms can effectively support orthodontists in achieving optimal treatment results. [24]

AI IN DIAGNOSIS AND TREATMENT PLANNING

AI has been gradually integrated into imaging diagnostics to enhance both sensitivity and specificity, making it a valuable tool in diagnosing diseases or conditions. With its proficiency in recognizing patterns, AI is particularly well-suited for analyzing imaging data. Despite significant progress in genetics, including next-generation sequencing, accurately diagnosing genetic syndromes remains challenging. Timely diagnosis of these syndromes is crucial for improving outcomes, and facial phenotypes often provide valuable diagnostic clues due to their association with many genetic congenital diseases.

AI has made notable contributions in this area, exemplified by the mobile app Face2Gene developed by FDNA. By comparing a patient's image with thousands in its database, Face2Gene identifies subtle patterns indicative of various syndromes, proving to be more effective than clinicians in diagnosing certain conditions, particularly in Caucasian and Asian populations.[25]

AI IN EXTRACTIONS

Orthodontic diagnosis involves a thorough assessment that combines both objective patient data and subjective evaluation of skeletal and dental misrelation’s. To address the inherent ambiguity in diagnosis, there is a growing need for automated diagnostic systems to provide more objective assessments.

AI-based diagnosis and treatment planning primarily employ artificial neural network systems, a supervised machine learning technique.

Different learning algorithm models have been developed to guide decision-making regarding extraction, demonstrating relatively high accuracy. For instance, Li et al. recently proposed a Computational neural model for extraction decisions, achieving an accuracy of 94.6%.

In a recent study, an artificial neural network (ANN) based AI model was utilized to determine the necessity of extractions prior to orthodontic treatment. The model exhibited impressive accuracy, achieving 80%. This demonstrates its efficacy as a decision-making tool. They offer valuable support, particularly for individuals with limited clinical experience. [26]

CEPHALOMETRIC X-RAY ANALYSIS

Since its introduction by Broadbent in 1931, cephalometric X-ray analysis has remained a fundamental aspect of orthodontic treatment planning. But the manual identification of landmarks remained a task for orthodontic practitioners.

Schwendicke et al. evaluated the precision of computerized landmark detection across various research endeavors. Their results demonstrated that most studies achieved landmark identification within a 2 mm tolerance limit, typically deemed accurate enough for clinical applications. [27]

The technical methods for automatic landmark identification can be categorized into four groups: (a) knowledge-based approach utilizing image processing techniques, (b) model-based approach, (c) soft computing or learning approach, and (d) combination of these approaches. Each approach comes with its own set of pros and cons, and varying degrees of precision or achievement rates have been observed.

In a separate investigation, AI-based deep convolutional neural networks (CNNs) were utilized for automated quantitative cephalometry to identify cephalometric landmarks. This system demonstrated superior performance in comparison to established standards, achieving an accuracy rate of 76%. [28]

Arik et al. utilized CNN to evaluate cephalograms, reporting a 5–15% increase in accuracy in landmark detection compared to traditional methods. Cephalometric analysis conducted digitally has enhanced diagnosis by reducing errors and saving time. Lee et al. examined the use of deep convolutional neural networks (DCNN) for analyzing cephalometric radiographs to differentially diagnose indications for orthognathic surgery. The use of DCNNs accelerated the process and enabled complex calculations to be performed more quickly.

Park et al. conducted a study comparing the performance of two algorithms, YOLO version 3 (YOLOv3) and Single Shot Multibox Detector (SSD), in identifying 80 landmarks. YOLOv3 demonstrated superior precision, computational efficiency, and error detection compared to SSD.[29]

DETERMINATION OF SKELETAL AGE

Assessing skeletal age based on skeletal maturation offers the benefit of utilizing existing lateral cephalometric X-rays, minimizing additional radiation exposure for patients. A modern approach called BoneXpert has emerged for automated bone age assessment. This technique employs feature extraction to outline bone edges in hand radiographs, facilitating bone age determination using both GP (Greulich Pyle) and TW (Tanner Whitehouse) methodologies. It has proven to be precise, with the mean difference between manual estimation and BoneXpert ranging from 0.19 to 0.73 years. Most studies utilizing AI for CVM stage determination utilize supervised learning, as these models tend to yield higher accuracy compared to unsupervised learning methods. Seo et al. conducted a study demonstrating prediction accuracies exceeding 90% across various AI algorithms. [30]

DECISION SUPPORT FOR ORTHOGNATHIC SURGERY

Given the subjectivity inherent in determining the need for orthognathic surgery, owing to variations in clinician experience and preferences, AI algorithms have emerged as a potential tool to assist clinicians in decision-making. Studies by Shin et al., and Choi et al., have utilized convolutional neural networks to predict the necessity for orthognathic surgery based on lateral and posteroanterior X-rays, achieving impressive prediction accuracies ranging from 91% to 96%. Notably, Choi et al.'s research expanded the diagnostic criteria to include additional parameters such as overjet and profile type, leading to a success rate of 96% in predicting the need for surgery. Moreover, Choi et al.'s AI model demonstrated the ability to predict extraction indication with a rate of accomplishment of approximately 91%, although performance varied between class II and class III patients. Although AI holds potential as an adjunctive tool in assessing the need for orthognathic surgery, it cannot currently substitute the expertise of experienced clinicians. Additional research is needed to enhance AI algorithms and verify their accuracy and applicability in clinical settings. (31)

MANAGEMENT OF IMPACTED CANINE

The management of impacted canines demands a comprehensive approach involving multiple disciplines to achieve optimal orthodontic and periodontal outcomes. Treatment duration is prolonged based on the extent of tooth displacement relative to neighbouring teeth. Bayesian Network (BN) offers an intermediary solution by utilizing X-rays in predicting impacted maxillary canines based on angular and linear measurements. The random forest algorithm demonstrated the maximum accuracy, effectively predicting canine eruption status with precision (83%). Wang et al. introduced a method named Learning-based multi-source Integration framework for Segmentation (LINKS), applied with CBCT to quantify maxillary variation in cases of unilateral canine impaction. (32)

FUTURE PROSPECTS:

The integration of AI, particularly deep learning, into dentistry holds great promise for advancing clinical practice and improving patient care. By analysing large datasets, AI can help researchers and clinicians gain a deeper understanding of complex oral diseases like periodontitis and oral cancers. AI's ability to uncover hidden patterns in genetic, environmental, and behavioural factors could lead to the identification of new risk factors, biomarkers, and potential treatments, enhancing the diagnosis and management of these conditions.

Before a dental appointment, AI systems can evaluate key patient data—such as age, gender, vital signs, medical history, and current health status—to generate tailored treatment recommendations. This personalized approach ensures that each patient receives the most effective and safest treatment options based on their unique needs, improving both clinical outcomes and patient safety.

AI also plays a crucial role in enhancing communication between patients and clinicians. By analysing patient preferences, treatment history, and concerns, AI can help clinicians better understand patient expectations and customize care accordingly. This can lead to improved patient satisfaction, better adherence to treatment plans, and more positive interactions between patients and their care providers.

In addition, AI can help reduce human error during dental procedures. By continuously monitoring the treatment process in real-time, AI can alert clinicians to potential issues—such as incorrect implant placement or improper use of instruments—before they escalate. This feedback helps ensure greater precision during procedures, reduces complications, and ultimately improves patient outcomes.

AI also facilitates interdisciplinary treatment planning by integrating input from various dental specialists. In complex cases that require input from orthodontics, periodontics, or implantology, AI can generate evidence-based treatment recommendations that align with the latest research and clinical guidelines. This ensures that all specialists involved in a patient's care are on the same page, leading to more coordinated and effective treatment.

When it comes to dental implant therapy, AI has the potential to standardize procedures by automating key steps such as implant design and placement. Using advanced imaging technologies like CBCT and intraoral scanning, AI can analyze a patient's anatomical data, such as bone density, tissue thickness, and emergence profile, to recommend the optimal implant position and design. This helps reduce the risk of complications and increases the success rate of implants.

AI can also improve prognosis predictions by continuously learning from clinical datasets and the latest scientific literature. This allows clinicians to predict patient outcomes more accurately, such as the likelihood of implant success or the recurrence of oral diseases. With this data-driven approach, clinicians can provide more precise counselling and develop better treatment plans tailored to each patient's needs.

Another significant advantage of AI in dentistry is its potential to streamline the insurance claims process. By allowing dental offices to upload radiographs, intraoral scans, and photos to insurance providers, AI can quickly assess and approve claims, eliminating delays and reducing administrative burdens. This ensures faster reimbursement, greater transparency, and allows patients to receive timely care without the uncertainty of insurance coverage issues.

AI also has the potential to enhance the overall patient experience. By learning patient preferences related to pain management, treatment duration, and communication style, AI can help create a more comfortable and personalized care environment. Additionally, AI-powered virtual assistants can assist with appointment scheduling, answering patient questions, and providing pre- and post-treatment instructions, making the entire dental visit more efficient and less stressful.

In summary, AI is set to transform dental care by improving treatment accuracy, enhancing patient-clinician communication, and streamlining administrative tasks. The ability to personalize care, reduce errors, and integrate advanced diagnostic tools will help clinicians deliver better outcomes. Moreover, as AI integrates with insurance systems and patient management platforms, it will make accessing dental care more efficient, transparent, and patient-centered, ultimately benefiting both practitioners and patients alike.[33]

CONCLUSION

Humans have long used machines to improve their quality of life, and machine learning has become a key player in this effort by creating autonomous systems that reduce the need for constant oversight. In orthodontics, AI integration enhances diagnostics and decision-making, reducing human error and providing additional tools for clinicians.

Training AI requires extensive and diverse sample data to generalize effectively, which is challenging in medical and dental fields due to the need for various patient profiles and imaging techniques. Current studies often suffer from limited expert input and lack clinical trials, which can lead to biased or less applicable results. Collaboration between AI developers and the scientific community is crucial, but AI tools must be carefully validated through routine manual checks to ensure their reliability.

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