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Artificial Intelligence in Pediatric Dentistry: A Review

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ABSTRACT
Artificial Intelligence (AI), a term introduced by John McCarthy in 1955, pertains to the capacity of machines to acquire knowledge and apply it to perform a range of cognitive tasks, such as language processing, reasoning, learning, and decision-making, essentially emulating human behavior. Machine Learning (ML), a term coined by Arthur Samuel in 1959, is a subset of AI that equips systems with the ability to autonomously learn and improve from experience without explicit programming. ML is instrumental in developing computer programs that can access data and autonomously learn from it. The incorporation of AI components into imaging machines can alleviate the workload and enhance efficiency. Pediatric dentistry benefits from various applications of artificial intelligence, and this paper provides an overview of these applications.

Keywords: AI; ML; Deep Learning; Pediatric Dentistry

INTRODUCTION:

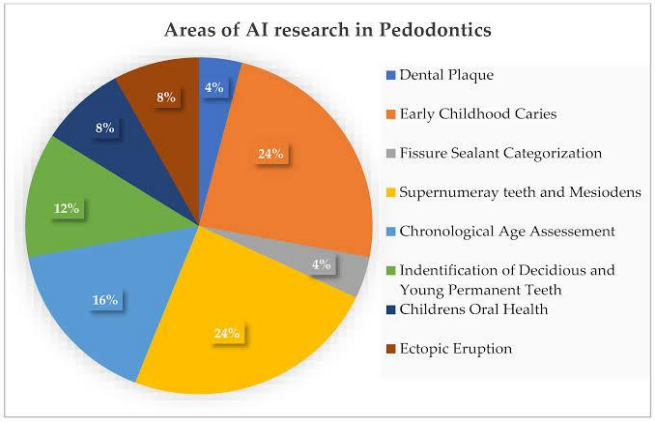
Artificial Intelligence (AI) has emerged as a transformative technology with significant potential in healthcare, including dentistry. This innovative technology is reshaping how dental professionals operate, from diagnosis and treatment planning to improving overall efficiency and precision in their daily tasks. In dentistry, two key branches of AI, Convolutional Neural Networks (CNN) and Machine Learning (ML), have found extensive applications, offering promising prospects for the future of dental practice.[1] Convolutional Neural Networks (CNN), a subset of deep learning, have proven invaluable for processing intricate and large dental images.[2] CNNs excel at recognizing patterns, structures, and anomalies in dental images, enhancing the efficiency and accuracy of diagnoses, particularly in complex cases involving X-rays and 3D scans. Machine Learning (ML) is another critical branch of AI in dentistry. ML models and algorithms improve the understanding and cognitive capabilities of dental professionals. They analyse patient data, medical records, and other relevant information to make predictions and treatment recommendations. This streamlines decision-making and enhances the accuracy of treatment plans.[3] The adoption of AI in dentistry has already made a significant impact. It has led to the development of robotic assistance, accurate dental image diagnosis, efficient pathology analysis, and streamlined record-keeping.

In pediatric dentistry, AI holds great promise as an ideal assistant for technique-sensitive procedures, offering real-time guidance, improving diagnostic accuracy, and creating a less intimidating experience for young patients.[4] As AI technology continues to advance, its applications in dentistry are expected to grow, ultimately reshaping the dental practice in the years to come.

APPLICATION IN DENTISTRY

AI has rapidly advanced in the field of dentistry, offering a range of applications that span diagnosis, decision-making, treatment planning, and outcome prediction. Diagnosis, in particular, has seen significant improvements through AI, reducing the workload on dentists while enhancing accuracy. Dentists increasingly rely on computer programs for decision support, and AI applications in dentistry continue to become more intelligent and reliable. However, the lack of standardized reporting and study design in dental AI research has led to the proposal of the MI-CLAIM (Minimum Information about Clinical Artificial Intelligence Modeling) checklist to enhance transparency and utility in the field. In dentistry, AI has found applications in various domains. For instance, it has enabled the early detection of dental caries, even in challenging cases, by analyzing radiographic and image data. AI algorithms can segment teeth, identify caries, and offer valuable predictions. Periodontitis diagnosis has also benefited from AI, addressing the limitations of clinical evaluation and helping in early detection. AI has been employed in orthodontics to aid in treatment planning and predict treatment outcomes, streamlining the decision-making process for both orthodontists and patients.[5] AI has made significant strides in the field of oral and maxillofacial pathology (OMFP), particularly in tumor and cancer detection using radiographic, microscopic, and ultrasonographic images. It has also played a role in managing cleft lip and palate, aiding in risk prediction, diagnosis, orthopaedics, speech assessment, and surgery. In prosthodontics, AI has revolutionized crown design by using AI models that generate custom-made designs for individual patients, significantly improving efficiency in the restoration process. AI also finds applications in shade matching and debonding prediction of CAD/CAM restorations. AI in Pediatric Dentistry can be used in the same way it is used in adults by providing primary and complete preventative and therapeutic oral health diagnosis, care, and consultation knowledge for infants and kids through adulthood. AI has the potential to solve discrepancies that may arise throughout the analysis of growth data, and AR augmented reality methodologies have been developed to educate patients and families about growth disorders and their treatments.[6]

APPLICATIONS OF AI IN PEDIATRIC DENTISTRY



IN DIAGNOSIS AND TREATMENT PLANNING

Artificial Intelligence (AI) has emerged as a game-changing technology in the realm of pediatric dentistry, offering a host of benefits tailored to the unique needs of young patients. AI revolutionizes how data is collected, organized, and utilized, enhancing the quality of care provided to children and adolescents. In this specialized field, AI plays a crucial role in pediatric dental practices, particularly with its focus on young patients. AI's efficient data management capabilities provide pediatric dentists with a structured and centralized system for organizing the extensive medical records of children. This ensures quick access to crucial information about a child's dental history, allowing for more personalized and child-centric care plans. Automation of routine tasks is especially beneficial in pediatric dentistry, where the well-being of young patients is of utmost importance. AI-driven chatbots can streamline appointment scheduling, answer billing inquiries, and communicate with parents, simplifying the administrative side of the practice. Within the clinic, AI can assist in diagnosing common pediatric dental issues, such as cavities, by analyzing X-rays and intraoral images. AI's decision support capabilities prove invaluable in pediatric dental care, helping dentists make well-informed decisions about treatments for young patients. By analyzing a child's dental and medical history, AI can suggest appropriate treatments and preventive measures, taking into account the unique needs and sensitivities of children. AI also excels in educating young patients and their parents. It can generate child-friendly educational materials, making it easier for children to understand their dental conditions, treatment options, and the importance of good oral hygiene. This empowers children to actively participate in their oral health care and encourages parents to enforce good dental habits. AI's predictive analytics can identify trends and potential risk factors in pediatric oral health. By recognizing patterns in a child's dental history and demographics, pediatric dentists can take early measures to prevent common dental issues in children, such as cavities or orthodontic problems. Remote monitoring becomes especially relevant in pediatric dentistry with AI-driven devices that help parents and dentists keep a close eye on a child's oral health between visits. For example, smart toothbrushes can provide real-time data on a child's brushing habits and oral hygiene, allowing parents and pediatric dentists to intervene promptly when necessary. In the context of research and development, AI can accelerate advancements in pediatric dental care. It can assist in analyzing data from clinical trials specific to children, facilitating the development of innovative treatments and preventive measures tailored to their needs. AI fosters a more participatory approach in pediatric dental care by engaging both young patients and their parents. By offering access to health data, age-appropriate educational resources, and decision support tools, AI ensures that children and their parents are well-
informed partners in maintaining optimal oral health.[7]

IN ASSESSING CHILDS ORAL HEALTH

Wang, Y. et al. have pioneered the development of a comprehensive toolkit utilizing Artificial Intelligence (AI) for the assessment of a child's oral health. This toolkit incorporates a short form (SF) designed to assist parents in evaluating their children's oral health status and the need for dental treatment. Notably, this innovative approach conceptualizes health as a holistic state, encompassing physical, mental, and social well-being. The accuracy and effectiveness of this toolkit are contingent on several critical factors. First and foremost, the toolkit's accuracy is intricately linked to the framing of questions posed to parents and caregivers.[8] The way questions are structured influences the quality and relevance of the data collected. Additionally, the knowledge quotient of both children and their parents plays a crucial role. Questions must be comprehensible to children and parents, ensuring that their responses provide

meaningful insights into the child's oral health status. The time of day when the survey is conducted is another pivotal factor. The child's condition and the parents' ability to provide accurate responses may vary throughout the day. Thus, conducting the survey at an appropriate time is essential to obtain reliable data. Above all, the success of this toolkit hinges on the development of the machine learning algorithm that powers it. The algorithm should be designed to effectively process and analyze the data collected from parents and caregivers. It must be capable of recognizing patterns and correlations within the responses to make accurate assessments of a child's oral health status and treatment needs. It's important to emphasize that the primary objective of this toolkit is to complement the work of dentists during dental examinations, rather than serving as a complete replacement for physical oral checks. AI is a powerful tool in the assessment process, streamlining data collection and analysis. However, the human expertise and clinical judgment of a dentist are irreplaceable when it comes to diagnosing and treating specific oral health issues.[9] Therefore, the AI-powered toolkit is intended to work hand-in-hand with dental professionals, enhancing their ability to provide comprehensive and individualized care for children's oral health. This collaborative approach ensures that the child receives the best possible care, with AI supporting and augmenting the diagnostic and treatment process.

AI IN DETECTING DECIDIOUS TEETH

In the field of dental diagnostics, the detection and numbering of teeth using dental radiographs serve as fundamental steps. Over the years, various image-processing algorithms have been developed to achieve accurate tooth classification and segmentation, focusing on different types of radiographs and employing a range of techniques. Researchers like Mahoor et al. presented an automated dental identification system based on Bayesian classification, demonstrating high accuracy in classifying and numbering teeth on bitewing radiographs. Similarly, Lin et al. recommended a tooth classification and numbering system using an image-enhancement technique, which performed effectively, even with challenging images. While earlier research primarily utilized threshold- and region-based techniques, recent advancements have increasingly leveraged deep learning, specifically Convolutional Neural Networks (CNNs). Eun et al. introduced a tooth localization technique based on oriented tooth proposals and a CNN for periapical radiographs. Miki et al. developed a CNN-based system for classifying seven tooth types using cone-beam CT images, achieving high efficiency. Oktay employed a modified CNN model for tooth detection on panoramic radiographs, with a focus on mouth gap detection and teeth placement. Jader et al. proposed a mask-region-based CNN method for tooth segmentation, showcasing high accuracy. Lee et al. used a full deep-learning mask-R-CNN method for automated tooth segmentation on panoramic radiographs, achieving high performance. Zhang et al. introduced a deep-learning CNN model with a VGG16 network structure for the detection and classification of teeth in periapical radiographs, showcasing precision and recall rates above 95%. Wirtz analyzed automated tooth segmentation on panoramic radiographs using a coupled-shape model with a neural network. Zakirov demonstrated coarse-to-fine volumetric segmentation of teeth using cone-beam CT images, emphasizing efficient handling of large volumetric images. Chen used Faster R-CNN to detect and number teeth on periapical radiographs, enhancing detection accuracy with post-processing methods. Tuzoff also employed Faster R-CNN in combination with the VGG-16 network for tooth detection and numbering, reporting performance similar to an expert. In a recent study, a Faster R-CNN model implemented with the Google Net Inception v2 architecture was utilized to develop an AI model capable of detecting and numbering deciduous teeth in pediatric panoramic radiographs. This innovation represents the first model capable of accurately detecting and numbering

each primary tooth in children, demonstrating high performance and the potential for significant advancements in pediatric dental diagnostics.[11]

IN ASSESSING CHRONOLOGICAL AGE

In the field of artificial intelligence (AI), researchers have made significant strides in the assessment of chronological age, with particular relevance to children and adolescents aged 4 to 15. This innovative approach combines digital pantomographic images and a novel set of tooth and bone parameters to determine age the feasibility of creating a pioneering methodology for chronological age assessment using digital pantomographic images. This approach incorporates an array of tooth and bone parameters, reflecting the capacity of AI to redefine age assessment techniques.[12] The newly developed methodology emerges as an effective and innovative tool for accurately determining the chronological age of children and adolescents, particularly those aged 4 to 15. This development carries significant implications for diverse applications in healthcare and forensics. It is important to recognize that the models are tailored exclusively to children and adolescents within the specified age range (4 to 15 years) and rely on the specific tooth and bone parameters Notably, the measurements obtained during the research are dimensionless, meaning they are based on proportions rather than specific units. This quality enhances the model's adaptability to images from various pantomographic cameras, expanding its versatility and applicability.To continue pushing the boundaries of age assessment, the research suggests exploring deep learning methods, comparing network characteristics with the newly developed models, and conducting sensitivity analyses of the variables necessary for metric age determination.
This commitment to advancement keeps AI at the forefront of age assessment techniques.[14]

AI IN EARLY CHILDHOOD CARIES

The application of Artificial Intelligence (AI) in the realm of early childhood caries (ECC) is demonstrating remarkable potential in predictive and diagnostic capabilities. Multiple studies have shown that machine learning algorithms can effectively predict ECC and caries risk in different populations. These algorithms exhibit high accuracy, sensitivity, specificity, and area under the curve (AUC) values, making them valuable tools for informing targeted preventive measures and enhancing clinical decision-making in dental caries management.One notable study by Liu et al. developed an automatic screening system using deep learning to detect ectopic eruption of maxillary permanent first molars. This innovative approach has the potential to improve the clinical diagnosis and management of ectopic eruption in children. Park et al. aimed to predict early childhood caries using machine learning models and observed that these models effectively identify high-risk groups among a large sample of children aged 1 to 5.[15] The findings suggest the feasibility of implementing AI-driven predictive models to enhance oral hygiene education and dental care for high-risk groups.Pang et al. targeted teenagers and constructed a caries risk prediction model, taking into account both environmental and genetic factors. The model demonstrated high discrimination ability, which could be pivotal in early identification of high-risk individuals, especially in a population known for high dental caries rates. In a similar vein, Karhade et al. employed automated machine learning (AutoML) to classify children based on their ECC status. AutoML, particularly when considering children's age and parent-reported oral health status, proved promising in classifying children in resourcelimited settings.Wu et al. [16] explored the use of machine learning in predicting tooth decay by analyzing bacterial communities in individuals' oral cavities, incorporating demographic and environmental factors to enhance prediction accuracy. These multifactorial models hold

potential for personalized preventive interventions targeting both bacterial species and individual-specific risk factors.

AI IN PEDIATRIC RESTORATIVE DENTISTRY

AI is rapidly revolutionizing the field of pediatric restorative dentistry, offering a myriad of benefits, including enhanced efficiency, precision, and aesthetics. At the forefront of this transformation is computer-aided design and computer-aided manufacturing (CAD/CAM) technology, which has become a cornerstone in restorative dentistry for children. This technology, driven by AI, empowers dental professionals to design and fabricate restorations with exceptional accuracy and speed. One of the primary advantages of AIenabled CAD/CAM technology in pediatric restorative dentistry is the substantial reduction in treatment time. Children, especially young ones, may find dental procedures challenging and may not tolerate extended treatment sessions. AI-driven CAD/CAM systems streamline the restoration process, allowing for quicker and more efficient treatment. Additionally, this technology facilitates the creation of custom-made restorations that precisely fit a child's dental anatomy. This tailored approach not only enhances treatment outcomes but also minimizes discomfort and the need for multiple visits. Moreover, AI, particularly in the form of deep learning, is a transformative subset of machine learning. Deep learning models are capable of extracting intricate and subtle patterns from dental images and radiographs. These models can identify essential features, such as lines, edges, corners, and macroscopic patterns in a hierarchical manner. In pediatric restorative dentistry, this capability holds great potential, particularly in conservative caries excavation and tooth preparation for accommodating restorations.[17]

AI IN DETECTION OF PLAQUE

The pioneering work of You, W. et al. in developing AI model-based deep learning techniques for the identification of plaque-affected primary teeth represents a significant advancement in the field of pediatric dentistry. Leveraging a Convolutional Neural Network (CNN) framework, their research is poised to revolutionize the way we approach plaque detection and management in primary teeth.This innovative AI model has undergone training on a substantial dataset of 886 tooth photos, enabling it to recognize and pinpoint plaque accumulation with a high degree of accuracy. One of the standout advantages of AI in plaque detection is its ability to swiftly analyze a large number of tooth images. This efficiency not only saves valuable clinical time but also allows for more frequent and thorough examinations. The potential to detect plaque early and track its progression offers an opportunity to implement preventive measures effectively. Continuous monitoring of plaque accumulation and dental health is another potential area of expansion. AI can be used to track changes in plaque status over time, enabling dentists to provide personalized
recommendations for improved oral hygiene and preventive care.[19]

AI IN ENDODONTICS AND ORTHODONTICS

The incorporation of Augmented Reality (AR) into the realm of dentistry is ushering in a new era of enhanced visualization and patient engagement. This innovative approach utilizes data derived from various diagnostic imaging modalities, such as periapical radiographs, computed tomography scans, and magnetic resonance imaging scans, to provide valuable real-time information to dentists, thus enhancing the diagnostic and treatment process. In dentistry, AR technology offers significant advantages. Dentists can overlay intricate anatomical details, such as root canals, directly onto the patient's oral cavity in real-

time, thereby reducing the need for constant reference to separate screens. This not only improves treatment precision but also maintains the dentist's focus on the clinical procedure, ultimately leading to improved treatment outcomes and reduced risks. Additionally, this real-time, three-dimensional visualization on the patient's body facilitates more effective communication between dental practitioners and patients, allowing for a better understanding of dental conditions, treatment options, and expected outcomes. Orthodontics, in particular, has seen notable advancements through the integration of AIdriven appliances and AR technology.[20] Personalized AI-driven appliances, designed to be more appealing to the younger generation, are gaining traction. These appliances are tailored to individual patient needs, offering an engaging approach to orthodontic treatment. Furthermore, AI algorithms and AR technology are combined to create customized treatment plans and appliances, improving efficiency and making orthodontic treatment more patient-centric. The use of AI in orthodontic treatment planning and appliance design ensures precision and predictability by analyzing extensive datasets and recommending personalized treatment strategies. AR complements this by allowing orthodontists to visualize expected treatment outcomes and effectively communicate them to patients. It also supports remote monitoring, where patients can capture images of their teeth using AR-powered apps, enabling orthodontists to assess progress and provide guidance remotely, reducing the need for frequent in-person visits.[21]

AI IN LOCAL ANESTHESIA

AI technology can enhance the quality of sonographic images used to guide local anesthesia procedures. Through image processing and enhancement, AI algorithms can refine the clarity and visibility of anatomical structures, making it easier for medical professionals to identify the target area for anesthesia. Improved image quality leads to more precise injections, minimizing the chance of complications. The use of AI in local anesthesia not only benefits medical professionals but also improves the overall patient experience. AI-guided procedures are often more precise, resulting in reduced discomfort, faster recovery times, and fewer complications. Patients can feel more confident in the safety and efficacy of local anesthesia, leading to a more positive perception of pediatric dentistry procedures.[23]

PREDICTION MODELS

GA and Artificial Neural Networks (ANN) have found use in prediction and interpretation of biological activities such as dental caries. If a proper training database representing values for a particular population is established, GA and ANN can be used to predict the sizes of unerupted teeth. An artificial neural network derived model was used in a study predict toothache on the basis of its association with toothbrushing time, daily tooth-brushing frequency, toothbrush replacement to pattern, use of dental floss, undergoing scaling and other epigenetic factors such as diet and exercise. The result was a toothache predictive model of great accuracy which recognized oral hygiene, adequate eating habits and prevention of stress as the essential factors in preventing toothaches.[21]

CHALLENGES

Implementing Artificial Intelligence (AI) in pediatric dentistry, while holding great promise, also presents several notable challenges. One of the primary concerns is the need for specialized and extensive datasets that cater specifically to the unique dental and oral health needs of children. Collecting such data, particularly from a pediatric population, can be time-consuming and resource-intensive. Additionally, the ethical use of AI in pediatrics, ensuring patient privacy, and obtaining informed consent from parents or

guardians is a critical challenge. Furthermore, the integration of AI into clinical workflows demands a shift in the traditional practices of pediatric dentistry, requiring dental professionals to adapt to and trust AI-driven tools for diagnosis and treatment planning. Moreover, ongoing updates and maintenance of AI systems, as well as ensuring their compliance with evolving regulations, can be cumbersome. Despite these challenges, the potential benefits of AI in pediatric dentistry, such as improved diagnostics and more efficient treatments, make it a field of great interest and ongoing development. Pediatric dentists and researchers must work collaboratively to address these challenges and harness the full potential of AI in promoting the oral health and well-being of young patients.[24,25]

ADVANTAGES AND DISADVANTAGES

AI-driven systems can analyze vast datasets of pediatric oral health information, facilitating early and accurate diagnoses of dental conditions. This leads to timely interventions and better treatment outcomes. AI tools assist dental professionals in streamlining routine tasks, such as image analysis, patient management, and appointment scheduling, thus increasing overall practice efficiency. AI can improve patient engagement through interactive educational tools and personalized treatment plans. Children and their parents can better understand their oral health conditions, making them active participants in their care. AI can predict and identify potential oral health issues, allowing for proactive preventive measures. This is particularly valuable in pediatric dentistry, where early intervention is crucial. AI enables precise treatment planning and customized interventions, ensuring that pediatric patients receive care tailored to their unique needs. The use of AI in pediatric dentistry necessitates the collection and storage of sensitive patient data. Maintaining patient privacy and data security is a significant challenge, especially when dealing with minors. Dental professionals must undergo training to effectively use AI tools, which can be time-consuming and require adaptation to new workflows. Resistance to adopting AI technology can hinder its effective utilization. Implementing AI solutions often comes with significant upfront costs for equipment, software, and training. Small pediatric dental practices may find it challenging to invest in these technologies. Pediatric dentistry inherently involves the care of minors, raising ethical questions about informed consent, patient autonomy, and the role of AI in decision-making for young patients. AI systems require continuous updates and maintenance to remain effective and compliant with changing regulations. This adds to the operational workload of dental practices.[1,4,25]

CONCLUSION

The integration of artificial intelligence (AI) and machine learning is gaining momentum across various domains, including the field of pediatric dentistry. AI holds the potential to address shortcomings in conventional dental care practices that have faced criticism. In dentistry, AI is emerging as a valuable tool for clinicians, enhancing patient care and simplifying complex protocols by delivering predictable results. It's worth noting that AI's underlying mechanisms can be intricate, and the initial setup costs are substantial. While AI in pediatric dentistry is in its early stages, it is rapidly advancing through ongoing research and development. Nonetheless, it's essential to recognize that, no matter how much technology evolves, artificial intelligence can never fully replace the role of human professionals in providing quality healthcare.

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