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A review on harnessing AI for precision dentistry: A new era in oral healthcare

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Abstract:
Artificial intelligence (AI) is transforming dental public health by improving diagnostic accuracy, treatment planning, and patient care. This review explores how AI enhances disease forecasting, treatment precision, and scalability through machine learning (ML) and deep learning (DL) algorithms, which analyze large datasets to predict disease trends. In dentistry, AI has revolutionized caries detection, classification of dental restorations, and treatment planning, often outperforming traditional methods. AI-powered tools like smart toothbrushes provide real-time feedback for oral hygiene, while AI applications in nutrition offer personalized dietary assessments that influence oral health. Additionally, AI driven models combining genetic and environmental factors enable precise caries risk predictions and targeted interventions. Ethical and legal challenges, such as data security and potential biases, need to be addressed to fully realize AI's potential. Despite these concerns, AI holds significant promise for improving patient outcomes and enhancing the efficiency of healthcare systems. Its integration into oral healthcare is poised to enhance the quality and accessibility of care, ushering in a new era of precision dentistry.

Keywords: artificial intelligence, deep learning, dentistry, machine learning, neural network

INTRODUCTION

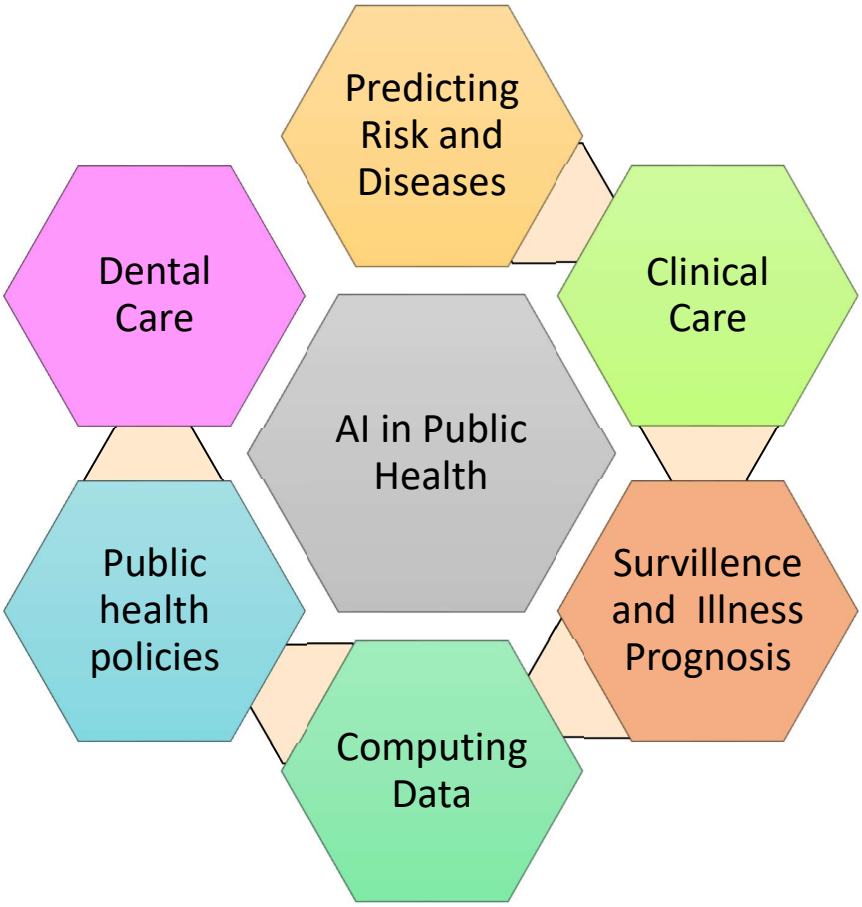
In many affluent settings, artificial intelligence (AI) is revolutionizing the delivery of health services, particularly in specialty care. This shift has been propelled by the increasing availability of large datasets and advanced analytical techniques that leverage this data.
Health technologies powered by AI can potentially resolve many system-related challenges, enhancing the efficiency, accuracy, and scalability of healthcare delivery [1].

Recent advancements in AI have also enabled the earlier detection of disease outbreaks compared to traditional methods, aiding in timely program planning and policy making. Given the considerable pressure on global health systems from various socio-political factors, the demand for efficient health service delivery—maximizing resources while ensuring patient safety—is increasingly urgent. The increasing aging population with numerous chronic illnesses and the escalating global healthcare costs add further strain to these systems [2].

Primary health care (PHC) is essential in meeting these challenges by effectively addressing health needs at both population and community levels. PHC is quickly advancing in both technology and health policies. Today, most PHC providers incorporate digital health information systems into their care delivery processes. Progress in computing and informatics has facilitated the incorporation of AI principles, like machine learning and deep learning, into these health information systems [3].

AI holds significant potential to enhance public health through improved treatment scalability, accuracy, and efficacy. AI can reveal insights and patterns that human analysts may overlook. However, its use in healthcare brings significant ethical and regulatory issues, such as data biases and privacy in AI systems. Moreover, the

advantages of AI in enhancing public health are unevenly distributed worldwide, resulting in disparities in access and implementation [4]. The role of AI in terms of Public Health has been summarized in figure1.



This review aims to explore how artificial intelligence is transforming dental public health. Itseeks to raise awareness of the ways in which AI enhances diagnostic accuracy, treatment planning, and patient care while addressing the ethical and legal challenges associated with its application.

SEARCH STRATEGY AND SELECTION CRITERIA

We carried out an extensive review utilizing PubMed, MEDLINE, and Google Scholar, incorporating peer-reviewed research articles published in English between January 1, 2008, and December 31, 2023. We focused on three main concepts: AI's role in patient safety, public health and dental public health. These concepts were aligned with the most suitable controlledvocabulary using Medical Subject Headings (MeSH), with additional free-text terms utilizedas necessary.

AI IN PUBLIC HEALTH

AI IN ILLNESS PROGNOSIS: REVOLUTIONIZING PUBLIC HEALTH

Artificial intelligence (AI) contributes significantly to public health by enhancing disease forecasting capabilities, allowing for better anticipation of infectious disease outbreaks and guiding effective public health interventions. Public health experts can now prevent outbreaks proactively and respond swiftly when they occur. Previously, traditional statistical methods like time-series analysis were employed to forecast disease occurrences. But with the development of AI, predictions can now be made with greater accuracy by utilizing a wider range of data sources and more complex algorithms [5].

AI'S EVOLUTION FROM CONVENTIONAL METHODS

In the past, illness forecasting entailed analyzing past data and projecting future patterns using statistical techniques. Even while these techniques were helpful, they frequently failed to convey the complexity and dynamic character of disease dynamics [6]. This field has experienced significant transformation due to advancements in AI, particularly through machine learning (ML) and deep learning (DL) algorithms [7]. Advanced algorithms enable the analysis of extensive datasets, including social media posts, electronic health records (EHRs), and sensor data, to detect trends and predict disease spread more accurately [8].

MACHINE LEARNING FOR PREDICTING DISEASES AND COMPUTING BIG DATAS

Machine learning algorithms significantly enhance AI's ability to predict illnesses by analyzing diverse data sources, such as social media and electronic health records (EHRs) [9]. These models identify early outbreak indicators and monitor disease progression. The availability of large datasets and advanced computational resources allows AI to process vast amounts of data from sources like wearable sensors, social media, and EHRs, uncovering hidden patterns and trends. This comprehensive analysis provides valuable insights for public health initiatives, enabling more accurate and timely disease predictions [10,11].

RISK PREDICTIONS USING AI IN PUBLIC HEALTH

Risk prediction is crucial in public health as it enables targeted treatment and prevention. By identifying individuals at higher risk of diseases, health systems can allocate resources more effectively and improve outcomes. Traditional methods, like manual data analysis, can be time-consuming and less accurate [12, 13]. AI, through machine learning algorithms, transforms risk prediction by analyzing large datasets such as electronic health records (EHRs) to detect patterns and predict disease likelihood. AI processes complex data quickly, identifying connections missed by conventional methods, and can combine genetics and clinical data to estimate risks for
diseases like cancer and cardiovascular conditions [1, 14, 15].

AI IN PUBLIC HEALTH SURVEILLANCE: TRANSFORMING ILLNESSTRACKING

Artificial intelligence (AI) has brought about a revolutionary change in public health surveillance, which was previously dependent on labour-intensive, error-prone human data collection. AI has become a potent instrument in this domain by utilizing the capacity to quickly evaluate enormous amounts of health-related data from sources such as social media platforms, sensor networks, and electronic health records (EHRs) [16]. AI systems, in contrast to traditional techniques, are excellent at seeing patterns and trends in real time, providing early alerts of impending disease outbreaks and epidemics. For example, organizations like the Centers for Disease Control and Prevention (CDC) uses AI to monitor illnesses like COVID-19, effectively tracking dynamics of spread by combining data streams [17].

Furthermore, artificial intelligence (AI)-driven methods like infodemiology and infoveillance examine online interactions and behaviours to offer timely insights into public opinion and illness patterns. Notwithstanding the fact that AI improves prediction accuracy and makes proactive public health treatments possible, issues with data integration and algorithmic bias still exist [18]. In the future, it will be crucial to establish ethical AI frameworks and integrate AI with emerging technologies to fully harness its potential in improving global public health surveillance [19].

AI IN DENTAL PUBLIC HEALTH

AI DEVELOPMENTS IN DATA LEARNING AND CLINICAL CAR

Global health data volume has grown exponentially in recent years, with estimates ranging from 153 exabytes in 2013 to 2,314 exabytes by 2020. This increase is mostly ascribed to developments in machine learning (ML), which is essential for efficiently evaluating large datasets [20]. Deep learning (DL) and other machine learning (ML) approaches have flourished because of the abundance of massive datasets, robust computing infrastructure, and open- source software frameworks. In order to analyze complex data like images (computer vision) and language (natural language processing [NLP]), DL uses artificial neural networks (ANNs). This allows it to gradually improve its capacity to handle tasks like object recognition, picture classification, and language interpretation [21].

Convolutional neural networks (CNNs) in computer vision have transformed diagnostics in the dentistry and medical industries by automating activities such as recognizing lesions from radiographs and pictures and finding anatomical landmarks from X-rays. By demonstrating accuracy on par with human specialists and requiring a substantially shorter processing time, these AI applications optimize the use of resources in healthcare contexts. However, issues that restrict model accuracy and generalizability continue to exist, such as data privacy concerns and the labour-intensive nature of categorizing data for supervised learning [22].

Natural language processing (NLP) enhances electronic health records (EHRs) and clinical reports by extracting valuable insights from unstructured text and speech data. By automating processes like medical coding and extracting relevant information from patient-provider interactions, natural language processing (NLP) models—including sophisticated designs like bidirectional encoder representations from transformers (BERTs)—improve clinical decision-making. Clinical care is improved by the integration of many data sources, including environmental and geographic data, wearable health monitoring, and predictive modelling [23].

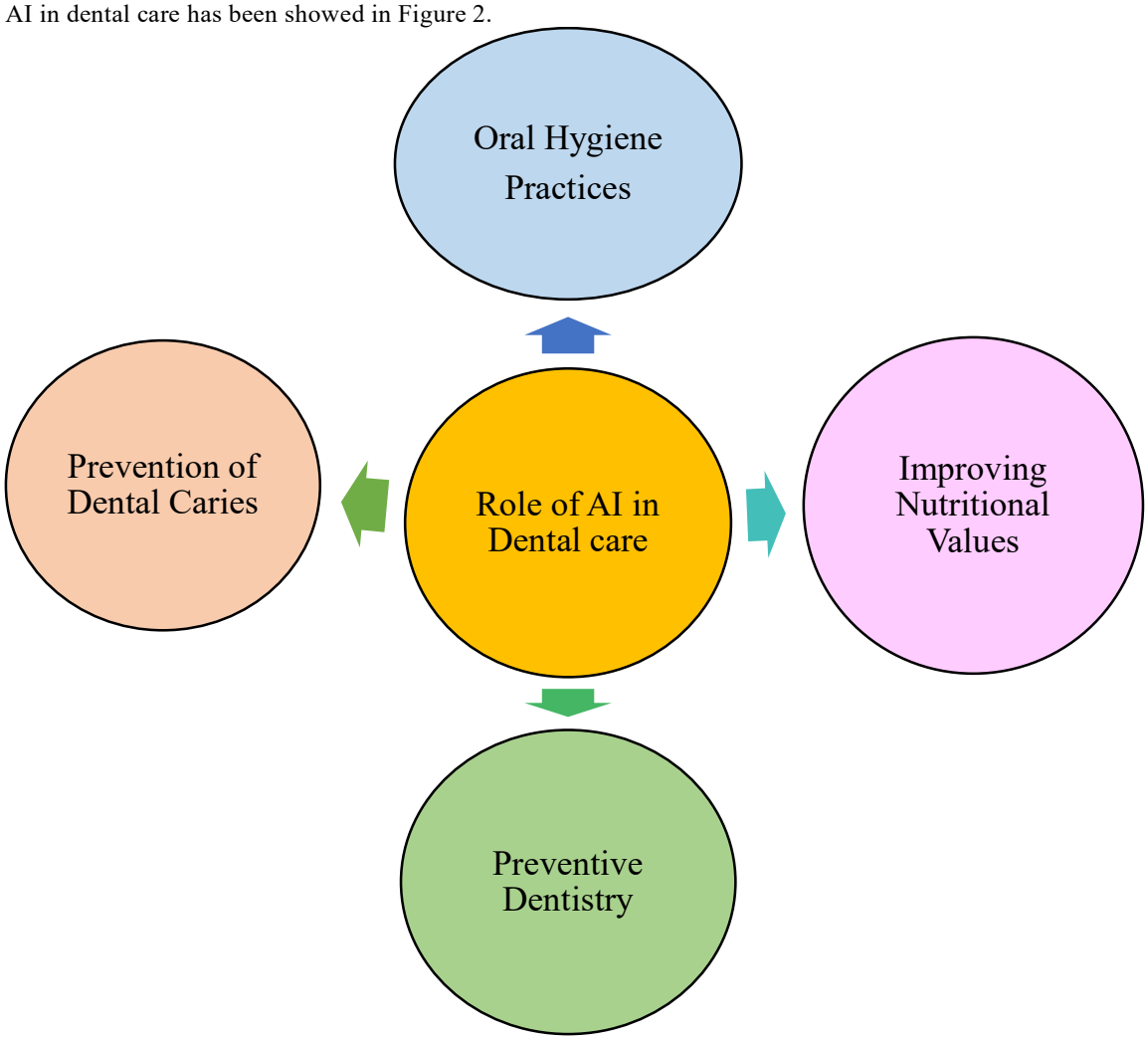
Future prospects for improving disease detection and treatment in dentistry and other medical contexts appear bright when omics technologies are combined with wearable health monitoring gear. These developments highlight how AI-driven data analytics is revolutionizing clinical operations, boosting patient outcomes, and directing preventative healthcare policies throughout the world [24].

AI DEVELOPMENT IN DENTAL CARE

Artificial intelligence, particularly neural networks, has significantly improved the accuracy and efficiency of restorative dentistry. Traditional methods for detecting dental caries, such as using dental probes and radiographs, rely heavily on a dentist's experience and are often subjective.

In brief some of AI in different fields of Dentistry,
Radiology: Neural networks enhance this process by analyzing radiological images like bitewing, periapical X-rays, and panoramic X-rays, making caries detection faster and more precise. Studies, such as those by Geetha et al., have shown that neural networks can achieve a caries detection accuracy of 97.1%, significantly outperforming traditional methods [25]. AI-powered algorithms can assist in detecting dental caries, periodontal disease, periapical lesions, and even oral cancers from radiograph with greater accuracy and speed than traditional methods [26].
Orthodontics: especially in terms of treatment planning, simulation, and patient monitoring. Aligner Design and Treatment Planning: AI algorithms are used to design clear aligners by predicting tooth movement and creating personalized treatment plans. AI-based apps can monitor treatment progress using photos taken by patients and help orthodontists track and adjust the treatment remotely, enhancing patient compliance [27].
Periodontal Risk Assessment: AI systems can assess risk factors, including genetic markers and lifestyle, to predict a patient's susceptibility to periodontal disease. Machine learning models can analyze data from patient history, clinical exams, and radiographs to predict disease progression and suggesting tailored interventions [28].
Oral surgery: Robotic surgery in dentistry, aided by AI, is gaining traction for performing precise, minimally invasive procedures, such as in the removal of tumors and implant surgeries. AI aids in preoperative planning for dental implants by analyzing CBCT scans to determine optimal implant placement and predict the success of the procedure [29].
Endodontics: Primarily focusing on diagnosis, treatment decision-making, and procedural automation. AI systems help in detecting endodontic diseases by analyzing radiographic images to identify periapical radiolucencies or root fractures. AI-driven robotic tools for root canal treatment are in development, improving precision and minimizing human error during the procedure [30]. AI also aids in detecting and classifying dental restorations. For instance, Abdalla-Aslan R et al.'s in their 2020 research demonstrated that AI algorithms detected about 93.6% of dental restorations on panoramic images and classified them into 11 categories based on shape and grey values [31]. Additionally, AI helps in treatment planning, as seen in Javed et al.'s study, where an artificial neural network (ANN) predicted the best excavation method for individual patients with 99.03% accuracy. This not only improves treatment outcomes but also reduces the need for re-examinations and minimizes pulpal trauma [32].
Prosthodontics: AI enhances the design and production of dental prostheses such as dentures, crowns, and bridges. 3D Printing and AI improves the design and quality of 3D-printed prosthetics by optimizing parameters based on patient-specific data. AI models predict the longevity of prosthetic materials and can guide the selection of materials for individual patients [33].

Overall, AI in restorative dentistry enhances diagnostic precision, streamlines treatment planning, and improves patient outcomes, marking a significant advancement over traditional dental practices. The role of AI in dental care has been showed in Figure 2.



USING AI TO IMPROVE ORAL HYGIENE PRACTICES AND OUTCOMES

Maintaining regular oral hygiene is essential to prevent oral bacterial colonization and lowering the risk of caries by removing plaque that builds up along the gingival edge and proximal tooth surfaces. Conventional techniques involve suctioning secretions and using a toothbrush, mouthwash, or a combination of the two. But technological developments, especially in the form of electronic toothbrushes, have completely changed how individuals practice dental care. These smart toothbrushes include built-in 3D sensors that can detect orientation and location in real-time and analyze brushing characteristics like frequency, length, and accuracy [34].

Dental practitioners are essential in highlighting the need of good oral hygiene. Adherence to oral hygiene habits among patients can be improved by integrating real-time monitoring and feedback capabilities. With the support of personalized preventive algorithms and risk prediction, smart systems with measurement and feedback devices can provide high-quality patient-centered care. These technologies empower patients to play a more proactive role in managing their healthcare and take greater control of their dental health [9].

In order to reduce gingival damage, smart toothbrushes using AI and ML algorithms can monitor brushing pressure, identify places that have been missed, log missing locations, and show the percentage of brushed surfaces on a dental map. By providing users with immediate feedback, they may enhance their brushing methods and achieve a more complete and gentle clean. This leads to the establishment of optimal oral hygiene practices and the avoidance of severe caries issues [12].

Nonetheless, a notable obstacle to the extensive integration of these sophisticated apparatuses is their elevated

price in contrast to conventional toothbrushes. Although they frequently have removable brush heads, they usually can't disinfect the stationary body—a drawback that needs more thought and invention. Notwithstanding these difficulties, AI-powered toothbrushes are a major development in oral hygiene that will improve dental health outcomes by providing more individualized and advanced treatment [35].

ARTIFICIAL INTELLIGENCE IN PREVENTIVE DENTISTRY: IMPROVING NUTRITION EVALUATION

Given the strong correlation between food and numerous oral disorders, including caries, one of the critical aspects of preventive dentistry is keeping an eye on patient's eating habits [36]. Nutrients are vital in preventive dentistry by supporting oral health and reducing disease risks. Calcium strengthens enamel and maintains the jawbone, preventing decay and periodontal disease. Phosphorus aids in remineralizing and repairing weakened enamel. Vitamin D boosts calcium absorption for stronger teeth and bones, reducing the risk of decay and gum disease. Vitamin C helps maintain gum integrity by promoting collagen production, while antioxidants like vitamins E and A reduce inflammation, protecting oral tissues from oxidative stress, which helps prevent gum disease [37]. Nutritional assessments help detect high sugar intake, which is a major cause of dental caries. By advising patients to reduce sugary foods and drinks, dentists can help prevent tooth decay [36].
More and more sophisticated AI algorithms are being used to assist with eating, evaluate oral disease risks associated with food, and comprehend overall eating patterns. In order to approximate food consumption, for example, one research successfully developed an electronic photographic approach and related picture processing algorithms. With the use of smartphone photos, users may enter data into FOODTM, another AI-based nutritional review system that calculates calories and macronutrient composition for accurate dietary assessment [38].

A novel methodological framework, termed the ontology for nutritional epidemiology, has been recently introduced in the discipline of nutritional epidemiology. With use of this technology, study findings may be integrated, made more visible, and connected, which enhances management and produces a more impartial nutritional evaluation [39]. Additionally, a nutritional evaluation system based on visual data has been developed by researchers, which uses a particular neural network to compute food volume [40]. Another study evaluated the efficacy of the image-based nutritional app Keenoa by analyzing the food diary entries of 100 participants over a three-day period [41]. The quality and amount of nurse's dietary intake have been evaluated using AI technology, indicating the possibility for creating AI tools and applications to track nutrient intake. This is especially important considering the worldwide obesity epidemic that we are now facing [42].
Several studies have investigated e-health applications related to cardiometabolic risk factors in female participants. These studies have employed machine learning techniques, including support vector machines, neural networks, and k-nearest neighbors, to identify observable characteristics [43] Cardiometabolic conditions, such as diabetes and hypertension, are closely linked to oral health issues like periodontitis and dental caries due to shared inflammatory pathways and systemic impacts on the oral environment and machine learning algorithms can help detect early signs by recognizing patterns between poor metabolic control and oral health deterioration.
Even with the advancements, more sophisticated AI algorithms are still required to propel this sector forward. Research on medical robots is not often integrated with current AI applications in nutrition. In order to close this gap, practitioners may need to adjust their perspectives and acquire new competencies in order to meet the expectations of upcoming research in the food and medical sectors [44].

ARTIFICIAL INTELLIGENCE AND DENTAL CARIES PREVENTION

Tooth decay, also known as dental caries, is a prevalent condition influenced by a combination of environmental and genetic factors. Even with the availability of sophisticated tools for assessing caries risks, there are limited studies showcasing models that predict caries risks considering new factors, such as human genetics. In 2016, dental caries was identified as the most frequent chronic disease worldwide, with treatment costs reaching $540 billion in 2015, heavily burdening dental clinics. These statistics highlight the urgent need for effective caries prevention measures [45].
Studies show a change in the prevalence of caries, with adolescents now being the most impacted group. Experts emphasize the importance of targeting at-risk individuals to prevent and control dental caries. AI-powered tools and applications for risk prediction models in early diagnostics and accurate assessments are very beneficial for adolescents at risk of developing caries [46].
Caries Risk Prediction Models (CRPMs) have shown success in improving patient care through noninvasive treatment approaches. These models are flexible, allowing patients to choose the level of intervention [47]. Three standardized models for caries risk evaluation are commonly utilized: American Dental Association Caries-Risk Assessment Tool, Caries Management by Risk Assessment, and Cariogram. These models predominantly

concentrate on environmental indicators and behavioral factors, including plaque index, levels of Streptococcus mutans, Lactobacillus, saliva flow, and salivary buffer capacity. However, the Cariogram, though advanced, has varying sensitivity (41.0% to 75.0%) and specificity (65.8% to 88.0%) in caries prediction [48].

Dental caries development is influenced by a combination of genetic and environmental factors. Environmental factors include dietary sugar exposure, poor hygiene habits, saliva characteristics, and dental plaque [49]. Genetic factors also play a significant role, with genetic risk variation score reported between 49.1% and 62.7%. Additional factors contributing to caries risk include dietary habits, immune system strength, saliva properties, taste preferences, and enamel formation. For instance, enamelin and Tuftelin genes have been linked to higher caries risk in the presence of high S. mutans levels [50].

CRPMs that consider only environmental factors may miss valuable information. Research suggests that combined models incorporating both genetic and environmental factors provide more precise predictions. An innovative CRPM from 2018, the first to use both predictors, includes factors like "cariostatic score", "plaque index" and "past caries experience" with machine learning algorithms enhancing prediction accuracy [51].

With nearly 1.8 billion new cases of early childhood caries (ECC) annually, AI combined with Interactive Oral Health Education via smartphone applications can improve ECC detection and implement novel treatment strategies. AI-powered CRPM models provide substantial informational support, enabling legislators to make informed decisions on prevention policies for high-risk groups [52]. AI can help identify and prevent further decay in the early stages of caries, characterized by white lesions on enamel, thereby protecting dental hard tissues. AI presents effective and trustworthy solutions for preventing caries, underscoring the significance of early detection and intervention in mitigating the worldwide impact of dental decay [53].

AI'S IMPLICATIONS FOR CREATING PUBLIC HEALTH POLICIES

AI has the potential to be a useful instrument in the creation of public health policy. The capacity to combine different datasets makes it possible to get insights that would be challenging to obtain using more conventional techniques.

It is possible to use algorithms iteratively, monitoring the outcomes of policies and using that information to improve and enhance succeeding policies. By utilizing these insights, policies that are more timely, effective, and well-targeted may be created. AI has significant potential for policymakers, yet its future adoption and implementation hinge on building confidence and providing education about its responsible and effective use [5].

CHALLENGES AND LIMITATIONS

Data security, privacy, and ethical considerations are only a few of the issues that need to be resolved in order to guarantee the safe and successful use of AI in public health. Patient data protection is essential, especially when utilizing data from several locations, which improves the robustness of AI models but presents serious privacy concerns [54]. AI in dentistry faces several challenges, including the need for large, standardized datasets, which are often unavailable or inconsistent due to many practices not having fully digitized records. Despite its potential to improve diagnostic accuracy, AI systems are prone to errors due to biases in training data, and ensuring their reliability in complex cases is difficult. Many dental practices also lack the infrastructure to implement AI, and integrating these systems into existing workflows can be technically demanding, requiring both investment and retraining of staff [55].

Federated learning and strict data de-identification mechanisms are two crucial techniques. AI systems must also be created with justice and parity in mind, avoiding prejudice and discrimination [56]. Policymakers may become skeptical about AI algorithms if they are opaque, which emphasizes the need for models that are easy to comprehend. Since the correctness and completeness of the data are what determine how reliable AI predictions are, ensuring high- quality data is another major difficulty [57]. To overcome these, cooperation and cutting-edge privacy protection strategies are essential. Collaborative efforts and advanced privacy protection techniques are crucial to overcoming these challenges and fully leveraging AI's potential in public health [58].

FUTURE DIRECTIONS

AI's application in public health for disease forecasting is expected to progress significantly in the future. One emerging field involves combining AI with other technologies like the Internet of Things (IoT) and wearable devices. These innovations can deliver up-to-the- minute data, improving the precision and promptness of AI forecasts. Moreover, advancements in explainable AI (XAI) techniques seek to enhance transparency and accountability in AI-driven forecasting systems by clarifying the decision-making processes of algorithms. In conclusion, AI has the potential to revolutionize disease forecasting in public

health by providing more accurate predictions, early warnings, and actionable insights. This capability can significantly improve public health responses, ultimately leading to better health outcomes. However, addressing the challenges of data quality, privacy, and ethical considerations will be crucial to fully realizing the benefits of AI in this field.

CONCLUSION

The integration of artificial intelligence (AI) in oral healthcare is revolutionizing diagnostics, treatment planning, and preventive care. In restorative dentistry, AI enhances the detection and classification of dental caries and restorations, offering more accurate assessments than traditional methods. Smart toothbrushes and other AI-powered tools provide real-time feedback and personalized care recommendations, improving oral hygiene practices. AI applications in nutrition monitor dietary habits affecting oral health, offering tailored assessments and risk predictions for dental diseases. AI-driven models in caries prevention, incorporating both genetic and environmental factors, offer precise risk predictions and effective, noninvasive interventions.

Despite the benefits, challenges such as ethical concerns, data security, and potential biases need to be addressed. Ensuring transparency and protecting patient privacy are crucial for AI adoption. Overall, AI has the potential to transform oral healthcare by providing accurate diagnostics, personalized treatments, and effective preventive care. Addressing challenges will help realize the full benefits of AI, leading to improved patient outcomes and more efficient healthcare systems. AI is poised to play a vital role in enhancing the quality and accessibility of oral healthcare globally.

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