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Smart Devices Powered By Artificial Intelligence and Internet of Things for Enhancing Oral Health Care

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Abstract

Oral health, an essential aspect of overall well-being, remains significantly underprioritized despite its strong association with systemic diseases such as cardiovascular conditions and diabetes. Traditional dental care often adopts a reactive approach, leading to late diagnoses and increased treatment complexity. However, the integration of Artificial Intelligence (AI) and the Internet of Things (IoT) into oral health monitoring is transforming this paradigm into one that emphasizes preventive, personalized, and continuous care. IoT-enabled devices—such as smart toothbrushes, intraoral sensors, and biosensors—collect real-time data on oral hygiene behaviors, salivary biomarkers, and physiological conditions. AI processes this data to deliver actionable insights, detect early signs of dental diseases, and suggest tailored interventions. In clinical settings, AI tools now analyze dental images, detect lesions, assist in orthodontics, and even design prosthetics with high precision. These technologies also promote patient engagement through personalized feedback, gamified interfaces, and virtual assistants.

Despite these advancements, several challenges hinder widespread adoption. These include infrastructural limitations, data standardization issues, privacy concerns, algorithmic biases, regulatory ambiguities, and cost barriers—especially in low- and middle-income countries. Nevertheless, ongoing innovations such as edge AI, 5G-enabled teledentistry, AR/VR applications,

and digital twins promise to make oral care more accessible and efficient.

This article underscores the transformative potential of AI and IoT in revolutionizing oral healthcare from reactive to proactive models. By addressing existing challenges through interdisciplinary collaboration, these technologies can pave the way for a more inclusive, accurate, and patient-centric dental care system globally.

Keywords: oral health, internet of things, artificial intelligence.

Abbrevations

AI – Artificial Intelligence

IOT – Internet of Things

ML – Machine Learning

NLP - Natural Language Processing

CAD – Computer Aided Design

CAM – Computer Aided Manufacturing

WHO – World Health Organization

EHRs - Electronic Health Records

LMICs - Low- And Middle-Income Countries

Introduction

Oral health is a critical component of general health and well-being, yet it remains one of the most neglected aspects of healthcare globally. According to the World Health Organization (WHO), oral diseases affect nearly 3.5 billion people worldwide, with untreated dental caries being the most prevalent health condition. Traditionally, oral healthcare has been reactive rather than proactive, often relying on periodic dental visits that may fail to detect early signs of disease.[1] As a result, conditions such as dental caries, periodontitis, and oral cancers are often diagnosed at advanced stages, leading to more invasive treatments, higher healthcare costs, and diminished quality of life.[1,2]

With the advent of digital health technologies, the paradigm is shifting toward preventive, personalized, and real-time health monitoring. Among these technologies, the Internet of Things (IOT) and Artificial Intelligence (AI**)** have emerged as transformative forces in healthcare delivery. IOT enables continuous data collection through interconnected devices and sensors, while AI offers the analytical power to process this data and generate actionable insights. In the domain of oral health, the integration of IOT and AI presents an unprecedented opportunity to revolutionize diagnosis, monitoring, and patient engagement.[2]

IOT-based dental devices ranging from smart toothbrushes and wearables to intraoral sensors can collect detailed information about oral hygiene practices, salivary pH, temperature, and bacterial activity. This data, when processed by AI algorithms, can help detect early signs of dental diseases, predict risk factors, and recommend personalized interventions. For instance, an AI-powered application might analyze brushing patterns captured by a smart toothbrush to identify inadequate coverage or overbrushing, and suggest corrective actions through a mobile app.[2]

Beyond personal oral hygiene, these technologies have applications in clinical settings as well. AI-driven diagnostic tools are now being used to analyze dental X-rays with accuracy levels comparable to experienced dentists, aiding in faster and more consistent diagnosis. Machine learning models can identify anomalies in dental images, classify lesions, and even estimate the progression of periodontal disease.[1]

As we move toward an era of smart healthcare, understanding the capabilities and limitations of IoT and AI in oral health is crucial—not only for dental professionals and technologists but also for public health policymakers and patients. This article aims to bridge the gap between technological innovation and practical application, emphasizing how smart oral health

monitoring devices can empower individuals, improve clinical outcomes, and contribute to a more efficient and equitable healthcare system.[3]

IOT in Oral Health Monitoring

Oral diseases such as dental caries, periodontal disease, oral cancer, and loss of tooth continue to be among the most prevalent non-communicable diseases globally. These conditions not only cause pain and discomfort but are also associated with systemic issues, including cardiovascular diseases, diabetes, and adverse pregnancy outcomes. Despite this, oral health often remains underprioritized in healthcare policies and systems, particularly in low- and middle-income countries.[4]

Several factors contribute to the persistence and growth of oral health issues. These include inadequate public awareness, limited access to affordable dental care, dietary changes (especially increased sugar consumption), and poor oral hygiene habits. Moreover, traditional dental care models heavily rely on clinical visits for diagnosis and treatment, which tend to be reactive rather than preventive. As such, many individuals visit dentists only after symptoms become severe, by which point intervention is more complex and costly.[5]

This gap in proactive care and monitoring can be significantly narrowed through the application of digital health technologies. The increasing penetration of smartphones, wireless connectivity, and wearable devices has created fertile ground for technology-driven solutions that support continuous health monitoring. In oral healthcare, this has led to the development of smart devices capable of collecting real-time data on hygiene practices and oral health conditions outside of clinical settings.[6]

For example, biosensors and saliva analyzers have shown promise in detecting biomarkers associated with dental caries, gingivitis, and even systemic conditions like diabetes. These biosensors can measure pH, glucose, lactate, and bacterial concentrations, offering an early warning system for oral and general health issues. When integrated with AI, these devices become even more powerful, capable of learning individual baselines and detecting deviations that may indicate the onset of disease.[5,6]

Technology also enhances patient engagement and education. Many oral health platforms gamify hygiene habits or use AI-powered virtual assistants to guide users through best practices. These systems promote accountability and consistency, especially among children, adolescents, and patients with special needs.[7]

The convergence of oral healthcare with IoT and AI technologies reflects a broader trend toward digital health transformation. These innovations support the global move from curative to preventive care, from generic to personalized treatment, and from episodic to continuous monitoring. As digital literacy and access improve globally, the potential for these technologies to democratize dental care and close the gap in oral health disparities becomes increasingly tangible.[5]

Application of AI in Oral Health Monitoring

Artificial Intelligence (AI) refers to the simulation of human intelligence by machines, particularly computer systems that can learn, reason, and self-correct. In dentistry, AI applications are transforming both clinical and preventive practices by analyzing large datasets to detect patterns, support decision-making, and personalize patient care. Combined with IoT, AI acts as the "brain" that interprets the massive amounts of data generated by smart devices, leading to more informed, efficient, and proactive oral health management.[8]

Types of AI Technologies in Oral Health

Several AI subfields are being leveraged in oral healthcare:[9]

Machine Learning (ML): Algorithms learn from historical data (e.g., brushing patterns, diagnostic images) to make predictions or classifications.

Deep Learning: A subset of ML that uses neural networks to process complex data such as dental radiographs and 3D scans.

Natural Language Processing (NLP): Enables AI-powered chatbots to interact with patients, offering guidance or answering oral health queries.

Computer Vision: Used for interpreting images and video feeds from intraoral cameras and radiographs for diagnostic purposes.

Diagnostic applications of AI[9]

a) Dental Radiograph Analysis

AI algorithms can analyze X-rays and other radiographic images to detect:

- Dental caries
- Periodontal bone loss
- Periapical lesions
- Impacted teeth
- Root fractures

Companies like Pearl, Overjet, and Videa Health have developed FDA-cleared AI tools that help dentists identify conditions with high sensitivity and specificity. These tools offer real-time annotations and severity scoring, reducing the chances of human error and standardizing diagnosis across practitioners.

Lesion and Tumor Detection

AI also assist in the early detection of oral cancer by analyzing images of oral mucosa captured via the intraoral cameras. Algorithms trained on thousands of annotated images can classify suspicious lesions and alert clinicians for further testing.

Orthodontics and Prosthodontics

AI models aid in:

- Automatic cephalometric landmark identification
- Predictive modeling for tooth movement
- Designing custom aligners or dental prosthetics AI-driven CAD/CAM software is streamlining the production of crowns, bridges, and implants with high precision.

AI in Personalized Oral Hygiene Monitoring[9]

When connected to IoT-enabled devices such as smart toothbrushes and wearables, AI algorithms offer personalized insights by:

- Tracking and scoring brushing technique and coverage
- Recommending improved brushing routes
- Predicting caries risk based on behavioral and environmental factors
- Reminding users to brush or floss based on past habits

Some platforms go a step further by adapting recommendations based on a user's age, health status, and even dietary habits, offering a true personalized dental health assistant experience.

Challenges, Ethic and Future Trends

Technical and Infrastructural Challenges[10]

Despite the rapid advancements in AI and IoT for oral health monitoring, several technical hurdles persist:

Connectivity and Compatibility: Not all dental practices have the infrastructure to support cloud-based platforms, smart scanners, or IoT-enabled devices. Integration with Electronic Health Records (EHRs) is often inconsistent or lacking.

Battery Life and Miniaturization: Oral health devices, especially intraoral sensors or smart dentures, face design constraints due to moisture, size, and the need for extended battery life.

Data Standardization: Diverse device manufacturers use different data formats and communication protocols, complicating interoperability and centralized data analysis.

These issues necessitate collaborative efforts between technologists, dentists, and regulatory bodies to establish industry-wide standards and improve usability.

Privacy, Security, And Ethical Considerations[11]

The collection and sharing of health data by AI and IOT systems introduce few significant privacy concerns like:

Patient Consent: Users must be fully informed about what data is collected, how it's used, and who has access to it.

Data Breaches: As oral health data becomes part of the broader health record, it is susceptible to cyberattacks. Encryption, blockchain, and AI-based cybersecurity are being explored to mitigate risks.

Bias and Fairness: AI algorithms trained on non-diverse datasets may exhibit performance bias across racial, gender, or age groups, potentially exacerbating health inequalities.

Automation vs. Oversight: Over-reliance on AI diagnostics without sufficient human oversight can lead to errors or misinterpretations, especially in borderline cases.

Ethical frameworks must ensure that AI augments, rather than replaces, human clinical judgment, and prioritizes equitable care delivery.

Regulatory and Legal Challenges[12]

Currently, regulatory agencies like the FDA (U.S.) and EMA (Europe) are developing frameworks for AI-based diagnostic tools, but these remain in flux. Challenges include:

Validation and Approval: Demonstrating the safety, efficacy, and reproducibility of AI-driven tools across diverse patient populations is complex.

Liability: In the case of a misdiagnosis or device malfunction, determining legal responsibility (device manufacturer, developer, or clinician) remains a gray area.

Cross-border Regulation: As AI and IoT tools become globally distributed, harmonizing data privacy laws and medical regulations is increasingly urgent.

Economic and Accessibility Barriers[13]

Cost of Devices: Many smart oral health technologies are expensive and inaccessible in low- and middle-income countries (LMICs).

Digital Literacy: Elderly populations or those in rural areas may lack the skills or infrastructure to effectively use smart devices.

Insurance Coverage: In many regions, dental insurance does not cover digital monitoring tools or AI-assisted diagnostics, creating disparities in access.

Efforts to reduce costs, provide education, and promote reimbursement models are critical for scaling these technologies equitably.

Future Trends and Opportunities[14,15]

The future of AI and IOT in oral health is promising, with several key trends on the horizon:

Integration with General Health Systems: Oral data will increasingly contribute to systemic disease monitoring (e.g., diabetes, cardiovascular health).

Edge AI: Moving AI processing closer to the device will enable real-time analysis without depending on internet access.

5G Connectivity: Faster data transmission will support high-resolution imaging and video consultations in teledentistry.

Augmented Reality (AR) and Virtual Reality (VR): For patient education, surgical planning, and immersive dental training.

Digital Twins in Dentistry: Virtual replicas of a patient's oral cavity will allow simulation of treatments and disease progression modeling.

As these innovations mature, the dental field stands to become not only smarter but also more preventive, predictive, and personalized. These real-world examples validate the effectiveness of AI and IoT technologies in a variety of dental settings from clinics to communities enhancing access, precision, and patient outcomes.[16]

Conclusion

The integration of Artificial Intelligence (AI) and the Internet of Things (IoT) into oral health care has marked a transformative era in dentistry. From everyday smart toothbrushes to advanced AI-powered diagnostic tools and salivary biosensors, the landscape of oral health monitoring is rapidly evolving. These technologies are enabling a shift from reactive, treatment-based care to proactive, preventive, and personalized oral health management.[17]

The key benefits are real-time monitoring of brushing habits and disease markers, Early detection of conditions like dental caries, periodontitis, and oral cancer, Remote care capabilities that enhance accessibility, especially in underserved populations and Data-driven diagnostics that reduce errors and improve clinician decision-making.[16] As these technologies become more affordable and widely adopted, they are likely to be integrated into routine dental care, both in developed and developing countries. The ongoing development of smart dental implants, edge AI devices, and mobile diagnostic platforms will further enhance the reach and efficacy of oral health systems.[17]

However, this revolution does not come without challenges. Issues of data privacy, bias in AI models, regulatory oversight, and cost barriers need to be addressed through collaborative, cross-sector efforts. Dentists, patients, developers, and policymakers must work together to ensure that these innovations are ethically designed, equitably distributed, and seamlessly integrated into clinical workflows.[18]

In summary, the combination of IoT and AI in oral health care signifies a paradigm shift toward safer, more intelligent, and more inclusive dental treatment rather than only a technical advancement. These technologies, which will revolutionize both the treatment and prevention of dental problems as innovation picks up speed, will enable patients and professionals to build healthier futures.[18]

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