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Can Artificial Intelligence Help to Prevent and Manage Oral Infections: A Review

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ABSTRACT

Introduction: This study aimed to answer “Can artificial intelligence help to prevent and manage oral infections? How can it help us? What we know and what we do not know?”.

Materials and Methods: Artificial intelligence-driven Internet of Things systems enable real-time monitoring of the oral environment and early identification of cariogenic and inflammatory factors. In the present narrative review, the authors used keywords such as “Artificial Intelligence”, “Biofilms”, “Dental Caries”, “Internet of Things”, and “Periodontitis”. They conducted a literature search via Google Scholar and PubMed from January 2015 to November 2025.

Results: Artificial intelligence algorithms have shown high accuracy in diagnosing oral and periodontal diseases, predicting microbial resistance, and optimizing antimicrobial therapies. Integration of artificial intelligence with antimicrobial robots represents a promising approach for biofilm detection, degradation, and targeted removal. These technologies collectively enhance personalized dental care and support preventive, data-based decision-making in dentistry.

Conclusion: Artificial intelligence and Internet of Things integration offer transformative potential in oral healthcare by improving early detection, prevention, and management of oral infections. However, further clinical studies, data standardization, and ethical considerations are necessary for safe and effective implementation of these technologies in dental practice.

Keywords: Artificial intelligence; Biofilms; Dental caries; Internet of things; Periodontitis.

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Introduction

Common clinical symptoms of bacteria-mediated oral infection may include the presence of dental cavities and periodontal disease. These conditions arise when there is an imbalance and disruption in the normal microbial community in the oral cavity, leading to inflammation and damage to the oral tissues [1,2]. When the oral hygiene is poor, microorganisms can colonize and form a biofilm—a layer of microorganisms that attaches to the tooth's surface and is surrounded by a self-produced extracellular polymeric protective matrix [3]. The initial step in biofilm development is the adhesion of microorganisms to the acquired glycoprotein pellicle on the tooth surface [4]. Once attached, these microorganisms produce acids that can harm tooth hard tissues, increasing the risk of tooth decay [5].

In response to the presence of the bacterial biofilm, the immune system activates immune cells such as neutrophils and macrophages [6]. Activated macrophages release pro-inflammatory cytokines such as interleukin-1β (IL-1β) and tumor necrosis factor-α (TNF-α). Associated with the pathogenesis of periodontal breakdown, these cytokines promote a pathway that leads to bone resorption by enhancing osteoclast activity through the up-regulation of RANKL/RANK [7]. IL-1β and TNF-α also contribute to collagen breakdown and tissue damage [8]. Clinically, these changes can be observed as bleeding on probing, increased pocket depth, bone loss, and the development of periodontal diseases such as periodontitis, peri-implantitis, and denture stomatitis [9].

Early identification of oral infection is crucial for prevention. Recently, sensors have been introduced that can be placed on tooth surfaces the surface of teeth to detect changes in the oral environment, such as pH levels and microbial flora. These sensors help control factors that contribute to oral infections and monitor these factors in the oral cavity [10]. They utilize advanced Internet of Dental Things technology (IoDT) to improve the diagnosis and prevention of dental problems, including cavities, oral cancers, periodontal diseases, and other oral conditions [11]. IoDT would also play a significant role in gathering and monitoring data in the oral healthcare system, providing dentists with new methods to assess risks [12]. By utilizing sensors to collect and monitor patients' oral health data, IoDT transmits and analyzes the data using artificial intelligence (AI) [10]. In recent years, AI-based technologies have shown promising results in developing antimicrobial strategies, offering possibilities for more accurate and effective treatments [13–15]. This study aimed to answer "Can artificial intelligence help to prevent and manage oral infections? How can it help us? What we know and what we do not know?".

Internet of Things

The Internet revolution over the past few decades has underscored the profound impact that emerging technologies can have across various scientific fields [16]. One particularly noteworthy advancement is the Internet of Things (IoT), which signifies an evolution of the Internet itself. The primary objective of IoT is to establish connections between objects anytime and anywhere, facilitating their interaction with a range of entities through diverse routes, services, and networks [17]. In remote healthcare monitoring, IoT is exemplified by intraoral sensors. These sensors are used to continuously monitor patient functions without disrupting patient care, demonstrating the practical application of IoT in healthcare [18]. Within the IoT framework, two computing technologies are particularly significant: edge computing and cloud computing.

Edge computing, which enables rapid processing of time-sensitive data, is especially beneficial for remote healthcare monitoring [19]. It allows immediate analysis and response to patient data, making it ideal for situations with limited connectivity. On the other hand, cloud computing is better suited for handling non-time-sensitive data, which can tolerate longer processing times [20]. Both of these computing technologies play a crucial role in the IoT ecosystem, particularly in healthcare. When a patient uses a sensor-assisted device for disease monitoring, the collected data is transmitted to their mobile phone or tablet, establishing a body area network. IoT devices, with their robust capabilities, play a crucial role in the secure and efficient monitoring, transmission, and analysis of patient data within cloud or edge computing networks, providing reassurance in remote healthcare monitoring [21].

Internet of Medical Things

Integrating the IoT with medical devices, known as the Internet of Medical Things (IoMT), not only presents many advantages for healthcare but also significantly enhances patient comfort. These benefits encompass cost-effective medical solutions and personalized care, all of which contribute to a more comfortable patient experience. The IoMT is organized into three distinct layers: the "things layer", the "fog layer", and the "cloud layer" [22]:

1. Things layer: The things layer, a cornerstone of the IoMT, includes devices such as patient monitoring tools, sensors, actuators, and medical records. This layer is crucial for gathering data from various wireless and monitoring devices, and it ensures that these devices are securely positioned to maintain the integrity of the collected information. Local routers connect these devices to the fog layer, which processes real-time data. Healthcare professionals can access patient data through this layer, significantly minimizing delays [22,23].

2. Fog layer: The fog layer serves as an intermediary between the cloud and the things layer. It comprises local servers and gateway devices that create a distributed fog networking framework. These servers process data in real time while ensuring security and data integrity. Measures such as encryption and access control are implemented to protect patient data. Gateway devices direct data from these servers to the cloud layer for additional processing. Healthcare experts can also retrieve patient data through this layer, further reducing delays in information access [22,23].

3. Cloud layer: A crucial component of the IoMT, the cloud layer provides data storage and computational resources for analysis and decision-making. It provides scalability and supports extensive medical systems, enabling IoMT to adapt to the needs of various healthcare settings. Medical data is stored in the cloud, enabling essential analytical tasks to be conducted as needed [22,23]. In summary, the IoMT enhances healthcare by enabling wireless connectivity, facilitating real-time data processing, and ultimately improving healthcare outcomes.

Internet of dental things

In addition to the medical field, IoT has also made its mark in dentistry, giving rise to the Internet of Dental Things (IoDT) [11]. The application of IoT in the dental field has brought about a significant revolution in diagnosis and treatment procedures. It has transformed the ideology and biomechanical aspects of dental care. The IoDT has dramatically improved the diagnosis and prevention of dental caries, periodontal diseases (such as gingivitis and periodontitis), oral cancers (including squamous cell carcinoma and salivary gland adenocarcinoma), and other oral conditions [10]. It plays a vital role in data collection and monitoring within the oral healthcare system, offering dentists new tools for risk assessment [21]. A key component of IoDT is the sensor, which collects various types of information and communicates it to designated locations through interconnected devices for further analysis and decision-making. This data collection and monitoring capability provided by IoDT is instrumental in enhancing oral healthcare and enabling dentists to assess risks using innovative methods [24]. The future of dental care will focus on disease prevention, with emerging technologies such as the IoDT playing a key role in preventing and effectively managing dental caries and other oral diseases [10,21]. The emphasis will be on prevention, early disease detection, and risk assessment. These preventive initiatives should be easy to implement, affordable, and effectively utilized at the community level [12]. IoDT has significant potential in various areas of dentistry due to its straightforward application. It enables rapid collection, transfer, and analysis of patient data, creating a technological link between patients and oral healthcare providers. By utilizing IoDT, dentists can improve their ability to detect and prevent oral diseases, ultimately enhancing patient outcomes and overall oral health.

Artificial intelligence

AI is making significant advances in dentistry, thanks to technological advances and the digitalization of dental practices [25]. Oral and dental diseases are prevalent, and AI techniques have the potential to identify and diagnose oral cavity pathology that may go unnoticed by human observation alone. As a result, AI is being increasingly integrated into dental practices [26]. AI encompasses various components, including machine learning (ML), artificial neural networks (ANNs), and deep learning (DL). ML enables machines to learn from data and solve problems without human intervention, and ANNs function similarly to the human brain. On the other hand, DL utilizes deep neural networks with multiple computational layers to analyze input data and automatically identify patterns, thereby enhancing feature detection [27]. In dentistry, data collected from IoDT-based wireless sensors is transmitted and analyzed using AI to address various issues [28]. For instance, Salagare et al. [10] introduced an IoDT-based intraoral wireless sensor to prevent dental caries. This sensor can monitor various oral cariogenic factors and is Bluetooth-connected to cellphones or tablets via a mobile app, enabling continuous, uninterrupted monitoring. The data monitoring process in the IoDT-based model consists of three stages [10]:

1. Oral data collection stage: During the initial stage, intraoral sensors are utilized to observe and monitor various elements within the oral cavity. These sensors can detect biofilm and measure temperature and pH

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levels. The data collected from these sensors is consistently and periodically gathered from patients.

2. Data transfer stage: The data collected from oral care activities is typically transmitted to a cloud server using mobile phone or tablet applications.

3. Analysis of data and storage: Analysis and storage are carried out using IoDT applications, AI, and tele-dentistry.

By leveraging AI and IoDT technologies, dental professionals can gather valuable insights from patient data, improve diagnosis accuracy, and provide more personalized treatment plans [10]. This integration of AI into dentistry holds great promise for enhancing oral healthcare outcomes.

Internet-based intelligent antimicrobial approach

Existing antimicrobial methods have limitations in effectively addressing the complex structure and biological properties of biofilms, which contribute to drug resistance. Moreover, these methods often fail to prevent the rapid re-establishment of biofilms when debris and bacteria are not removed [29]. Therefore, there is a need for novel technologies that can target the biofilm structure, eradicate the bacteria within it, and eliminate the degraded substances. One potential solution to this challenge is the use of robotics, specifically catalytic antimicrobial robots [30]. These robots are equipped with catalytic capabilities that enable them to eliminate bacteria chemically and degrade the biofilm matrix [30]. Additionally, their magnetic actuation enables them to remove biofilm from surfaces physically. By combining these functionalities, catalytic antimicrobial robots have the potential to provide an effective means of combating biofilms and preventing their reformation [30].

Hwang et al. [30] conducted a study where they employed catalytic antimicrobial robots for the effective treatment of biofilms on both biotic surfaces, such as teeth, and abiotic surfaces, such as implants. One notable application of these robots was demonstrated in addressing the challenges posed by the isthmus region of teeth. The isthmus is a narrow gap, typically a few hundred micrometers wide, located between root canals, where bacterial biofilms commonly form. Existing methods cannot physically access or disinfect this specific anatomical area. They demonstrated that the catalytic antimicrobial robots could actively move within the isthmus and disrupt biofilms [30]. The integration of smart catalytic antimicrobial robots, IoDT-based intraoral wireless sensors, and AI enables a comprehensive approach to collecting and analyzing data from the oral cavity and eliminating specific biofilm (Figure 1). The IoDT-based sensor collects information on microbial species and factors that contribute to tooth decay [10]. This data is then fed into AI systems for analysis. AI plays a crucial role in analyzing large datasets containing information on microbial genetic characteristics and their responses to antimicrobial agents. By examining these datasets, AI can identify patterns and genetic mutations associated with antimicrobial resistance [31,32]. This information enables AI to predict which microorganisms are more likely to develop resistance in the future [32].

AI can also simulate microbial evolution to understand potential resistance mechanisms better. By leveraging databases, AI can identify commonalities among drug-resistant strains, providing insights into how resistance develops and spreads. Additionally, AI can monitor microbial responses in real time, enabling early detection of reduced susceptibility or resistance [33]. This capability allows for AI to promptly suggest adjustments to treatment strategies, ensuring appropriate measures are taken to combat resistance. Ultimately, AI can recommend personalized antimicrobial treatment plans based on the specific infection and the predicted likelihood of resistance in the infecting microorganism [34]. This information is then sent to smart catalytic antimicrobial robots, which are designed to precisely and controllably degrade, kill, and remove biofilms with remarkable efficiency.

The catalytic antimicrobial robots utilize iron oxide nanoparticles with dual catalytic and magnetic functionality. These nanoparticles generate bactericidal free radicals, break down the biofilm's exopolysaccharide matrix, and remove fragmented biofilm debris using magnetic-field-driven robotic assemblies. Therefore, integrating smart catalytic antimicrobial robots, IoDT-based intraoral wireless sensors, and AI enables the collection and analysis of oral-cavity data, leading to more effective antimicrobial treatment strategies and targeted biofilm removal [30].

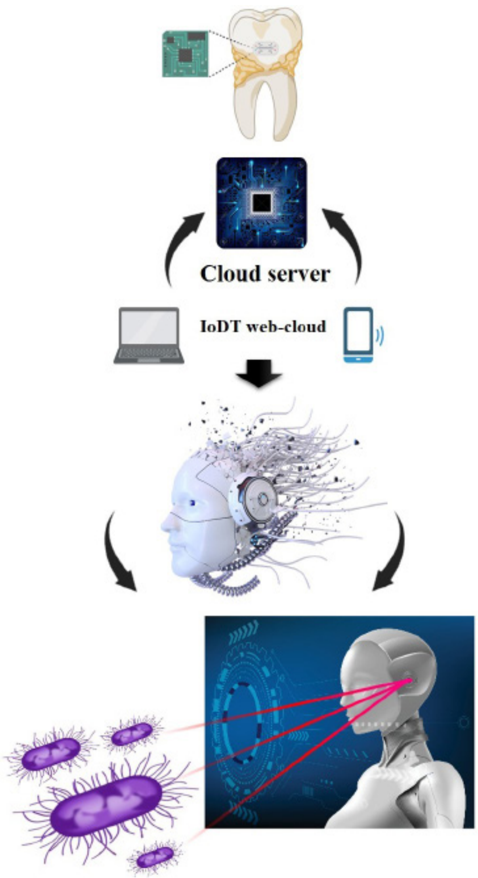

Figure 1. Internet-based intelligent antimicrobial approach (IoDT, Internet of dental things).

Conclusion

In conclusion, the integration of IoDT-based intraoral wireless sensors and AI can bring about a significant revolution in the field of identifying microbial agents and cariogenic factors, as well as in early detection, prevention, and timely action. This advancement enables the prevention of tooth decay through the early identification and control of cariogenic factors. By accurately identifying the specific microorganism species present and implementing appropriate antimicrobial protocols, the development of resistant strains can be effectively prevented. This integration of technology and artificial intelligence paves the way for improved oral health outcomes and could transform the way we approach dental care. Despite these promising advancements, challenges remain regarding the standardization of data, ensuring patient data privacy, and the need for extensive clinical trials to validate the efficacy and safety of these autonomous robotic systems in daily practice.

Conflict of Interest

There is no conflict of interest to declare.

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