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Artificial Intelligence and Microbiology

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Abstract

The concept of Artificial Intelligence (AI) is increasingly important in the healthcare sector today. Components of AI such as machine learning and deep learning are being utilized in various applications within the field of microbiology. This study examines the uses of AI in microbiology and its role in healthcare applications.

Machine learning enables computer systems to analyze data using algorithms that mimic human intelligence, while deep learning processes information through multi-layered artificial neural networks. These technologies are used in many areas such as microbiological diagnosis, drug discovery, infection control, and patient monitoring.

For instance, AI-supported systems are used in microbiological diagnosis to shorten diagnosis times and increase accuracy compared to traditional methods. Additionally, smart systems developed for preventing hospital-acquired infections alert hospital staff, thus reducing the risk of infection.

AI also plays a significant role in the diagnosis of microorganisms such as viruses and fungi. Especially, AI-supported image analysis methods are utilized for rapid and accurate diagnosis. However, there are some challenges in the use of AI. Issues related to data privacy and ethics are among the factors limiting the applications of AI in microbiology and healthcare. Furthermore, the cost and complexity of algorithm implementation pose additional challenges. By discussing the applications of AI in microbiology and its potential in the future, this study sheds light on innovative developments in the healthcare sector.

Key words: *Artificial Intelligence, Healthcare, Medical microbiology*

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Introduction

The concept of Artificial Intelligence (AI), which first emerged in 1956, refers to digital systems that attempt to solve problems using algorithms that mimic human intelligence and continuously improve themselves with processed information. Today, with the increase in the amount of data entered, the use of more powerful coding languages, and the utilization of advanced algorithms, AI has spread to a wide range of sectors and begun to benefit many industries. In addition to its presence in various fields such as tourism, real estate, public services, navigation, facial recognition, smart cars, chatbots, search engines, and social media, its significance in healthcare applications is increasing day by day (1).

An AI system, composed of many components, is advanced with machine learning and further enhanced in problem-solving ability through deep learning. These components can be examined under the main headings of machine learning, deep learning, natural language processing, neural networks, image processing, and cognitive computing. In fact, machine learning lies at the core of these intertwined components.

Machine Learning

Machine learning is the fundamental component of AI systems, teaching computers to process data like how humans learn and think. The basic aim of machine learning is to teach the computer to make predictions and inferences. The first step in machine learning is to create a model with algorithmic data. Then, this model is trained and integrated into the application to be used. Subsequently, the suitability of the output data of the model is checked. In machine learning, there are two main components used to create these models: supervised learning, which involves example data containing the algorithm's input and output, and unsupervised learning, which involves algorithms scanning new data to establish connections between unknown inputs and predefined outputs (2).

Deep Learning

Deep learning is a subset of machine learning that learns information by using multi-layered artificial neural networks, processing data in a way very similar to how neurons in the human brain function. Each artificial neuron uses software packages called nodes that perform mathematical calculations. When these neuron networks receive a data input, they pass it on to lower layers. With each new data passed through these hidden layers, the information is processed at different levels. This processed information emerges as a response from the output layer, which is the final layer (2).

Applications of Artificial Intelligence in Healthcare

With the advancement of technology, AI has become highly integrated into the field of healthcare. Examples include the development of medical diagnoses, acceleration of drug discovery, management of health data, robotic surgery, patient monitoring, and imaging.

Artificial intelligence-supported image technology also holds significant utility in the field of radiology. AI, such as Aidoc, employs deep learning algorithms to store data entirely in cloud servers, eliminating the need for a physical device outside the imaging device itself (3). In addition to radiology, AI is also utilized in the field of surgery, with robotic surgery serving as a prime example. Robotic-assisted surgery, also known as the da Vinci system, facilitates complex techniques with multiple arms, provides clearer images with high-resolution cameras, and offers advantages such as minimal invasive intervention resulting in less blood loss, faster recovery, and reduced risk of infection (4).

The increasing frequency of emerging infections and the concomitant rise in drug resistance necessitate the acceleration of new drug discovery. Selecting the right target is crucial for the successful development of a drug molecule. In the disease process, numerous proteins are involved, with some being overexpressed. Artificial intelligence-supported programs like AlphaFold analyze the three-dimensional structures of target proteins in drug discovery, accurately delivering the drug molecule to the correct target, thereby contributing to the success of this process (5).

Pandemics caused by infectious diseases such as the Spanish flu, Ebola, and Corona Virus Disease (COVID-19) have resulted in millions of deaths. It is known that the Spanish flu infected one-third of the world's population in the 20th century, and it is indicated that the Influenza A viruses seen today are different variants of this pandemic (6). Therefore, the control, prevention, and treatment of epidemic diseases are crucial for the future of humanity. AI-based applications play an important role in monitoring infectious diseases.

One of these applications involves the use of a relatively new data class called the Internet of Things (IoT). IoT is an internet network that can be installed on devices such as smartphones and smartwatches that we use in our daily lives, allowing them to collect data. The collected data is used to better understand infectious diseases, the mechanisms of infections, treatment resistance, transmission, and to develop vaccine designs (6).

One useful application is the deployment of thermal cameras in airports. These cameras can detect individuals with elevated body temperatures, thereby identifying potentially infected individuals (6).

Usage in Microbiology

The history of tests related to the detection of microorganisms dates back to before the publication of Koch's postulates in 1890. These tests have evolved from simple culture methods such as Petri dishes to serological tests, matrix-assisted laser desorption/ionization time-of-flight mass spectrometry (MALDI-TOF), and modern molecular methods like next-generation sequencing, and continue to advance (7). However, human limitations in processing capacity and the consequent use of a limited range of parameters also restrict interpretation and observation abilities. In this context, AI can provide more precise and versatile results without being subject to any limitations (1, 8). It can help minimize the risk of misdiagnosis in the laboratory, such as due to similarities in colony color and shape (9). Moreover, it aids in saving labor and time while ensuring more accurate and reliable results (1).

One of the threats to human health is nosocomial or hospital-acquired infections. Many pathogens that cause nosocomial infections are naturally resistant to empirical drugs, making them untreatable with routine treatment protocols. Most individuals affected by nosocomial infections are elderly, newborns, or individuals with immunodeficiency. Fortunately, when correct treatment and prevention protocols are applied, these diseases can be prevented by up to 70%. A software called AITSM (Artificial Intelligence Thermal Sensing Monitor) has been developed to monitor whether these protocols are correctly implemented. AITSM tracks hospital staff's protective clothing via cameras and can be installed on smartphones, providing alerts through voice commands. It serves as an example of AI used for monitoring and ensuring compliance with infection control protocols in healthcare settings (10).

AI integrated into molecular diagnostic methods also finds applications in whole genome sequence analysis. AI capable of detecting antibiotic resistance genes in a sequenced bacterial genome can inform us about which antibiotics the bacterium is resistant to and which ones it is susceptible to, without the need for conducting antibiotic resistance tests on the bacterial species. This capability helps save time and labor by providing insights into the bacterium's antibiotic resistance profile directly from its genome sequence (8).

MALDI-TOF (Matrix-Assisted Laser Desorption/Ionization Time-of-Flight) is another laboratory technique where smart software applications are used. In MALDI-TOF, biomolecules such as proteins, sugars, peptides, and large polymers are ionized after which they are passed through an electric field to extract protein profiles. These profiles are then compared with reference profiles in the system to identify species and genera (11).

MALDI-TOF can also be used for predicting antibiotic resistance. In a study, machine learning algorithms such as decision tree, k-nearest neighbors, random forest, and support vector machine (SVM) were able to distinguish between hospital-acquired infections caused by vancomycin-intermediate *Staphylococcus aureus* (VISA) and heterogenous VISA from vancomycin-sensitive strains (12). Another resistance study focused on hospital-acquired infections caused by vanB positive vancomycin-resistant *Enterococcus faecium* (VRE). With high specificity (98.1%) and sensitivity (96.7%), the study successfully differentiated VRE from susceptible strains. Additionally, the study measured the similarity degrees of 66 VRE isolates that could not be distinguished using PFGE (Pulsed-Field Gel Electrophoresis) method (8).

Artificial Intelligence for Bacteria

Bacteria are single-celled prokaryotic microorganisms, typically ranging in size from 0.1 to 10 micrometers, with most having a cell wall made of peptidoglycan. They can be found in various forms, including cocci (spherical), bacilli (rod-shaped), cocobacilli (oval-shaped), vibrio (comma-shaped), and spiral. To differentiate between bacteria, their microscopic shapes, colony morphologies, staining and biochemical properties, as well as differences in genetic sequences, are utilized.

In a study conducted by Glasson et al. (13), traditional plate reading and digital imaging were compared. An Automated Plate Assessment System (APAS) was utilized for urine samples, and differences between the traditional methods were evaluated. APAS demonstrated a sensitivity and specificity of 99% and 85%, respectively, in diagnosis. It was able to detect 99% of colonies on blood agar plates and 99.5% on MacConkey agar plates. Additionally, APAS showed agreement with microbiologists in 92.1% of plate interpretations, with a sensitivity of 90.8% and specificity of 92.8% for case definition (13).

In a similar study, Ma et al. (14) employed AI for the detection of bacteria on food, focusing on the analysis of morphological differences in microcolonies. Using the YOLOv4 (You Only Look Once) algorithm, it was found that the detection of *Escherichia coli* (*E. coli*) was 30 frames per second faster compared to the basic microscopic detection method. Additionally, the study showed that the YOLOv4 algorithm could distinguish *E.*

coli from other bacteria in mixed bacterial cultures (14).

One of the applications combining AI with clinical practice is computerized tomography (CT) and X-rays. In studies on the diagnosis of pulmonary tuberculosis (PTB) caused by *Mycobacterium tuberculosis*, AI-assisted chest X-rays were reported to provide results close to those of clinicians. In a comparative study, the performance of an automated AI image reader and manual image reading was evaluated on 47 PTB-positive patients. While expert doctors misdiagnosed 14 cases, AI only misidentified 5 cases (15).

Artificial Intelligence for Viruses

Viruses are obligate intracellular parasites that are so small that they can only be seen with an electron microscope. They contain single or double-stranded DNA or RNA surrounded by a protein coat called a capsid. Some species additionally possess an envelope and harbor surface antigens along with adhesion proteins. Due to the difficulty in their cultivation, requiring cell culture in vitro, much like bacteria and fungi.

Although viruses exhibit distinctive features in terms of their different structures and shapes, difficulties in isolation and imaging have led to the widespread preference for studying the effects of viruses on cells (cytopathic effect) for diagnosis.

After the COVID-19 pandemic, which affected the entire world in 2019 and led to 774,834,251 cases and 7 million deaths according to the World Health Organization (WHO) by 2024, the early diagnosis of viruses has become even more crucial (16). For early diagnosis of COVID-19, Widodo et al. (17) developed an application that can diagnose the disease based on clinical symptoms such as fever, fatigue, cough, shortness of breath, sore throat, chest pain, nasal congestion, runny nose, and diarrhea. Researchers can input the encountered symptoms into the system and fill in the remaining systemic information to obtain results. The application achieved a high accuracy rate of 94.2% in diagnosing COVID-19 (17).

In another study by Sitaula et al. (18), symptoms of the monkeypox virus were taught to the Xception DL AI software with images. Subsequently, a group consisting of a total of 1754 individuals including those with measles, monkeypox virus, avian influenza, and healthy individuals had their photographs entered into the system. The software accurately predicted and classified the sick individuals from these photos with an accuracy rate of 86% (18).

Artificial Intelligence for Fungi

Fungi, unlike viruses and bacteria, have eukaryotic cell structures. They have cell walls like bacteria, but these walls are composed of chitin. They contain ergosterol instead of cholesterol in their cell membranes, distinguishing them from other eukaryotes. Morphological distinctions are made based on colony shape and sporulation. They can be unicellular or multicellular, existing in mold or yeast forms.

Although fungal diseases may not receive much attention from the general public or scientists, they can cause serious infections, especially with the increasing number of individuals with underlying serious illnesses and immunodeficiency conditions (such as transplant patients, AIDS (Acquired Immune Deficiency Syndrome) patients, cancer patients, and those undergoing chemotherapy).

Diagnosing fungal diseases is challenging due to the similarity in their morphologies, making it difficult to make definitive and rapid diagnoses. AI shortens this diagnostic process, particularly contributing to survival rates in immunosuppressed patients (1, 19, 20).

In a study utilizing AI, fungal colonies stained using a simple staining method were identified with the help of a camera capable of distinguishing their morphologies. A database was created containing species from the *Candida* genus (*Candida albicans*, *Candida glabrata*, *Candida tropicalis*, *Candida parapsilos*is, and *Candida lusitaniae*), the *Saccharomyces* genus (*Saccharomyces cerevisiae* and *Saccharomyces boulardii*), and the *Basidiomycetes* genus (*Malassezia furfur* and *Cryptococcus neoformans*). The study shortened the diagnosis time of the disease by 2-3 days (19).

In a similar study, a database was created introducing sporulation shapes. Cultures of *Penicillioides*, *Restrictus*, *Versicolor*, *Cladosporium*, and *Eurotium* fungal species were photographed using a microscope and camera after sporulation. The system was trained with 30,000 photos, and 10,800 photos were used for testing. In this study utilizing convolutional neural networks (CNNs), the accuracy rate was found to be 94.8% (20).

In a study focused solely on *Aspergillus* species (*A. clavatus*, *A. flavus*, *A. terreus*, *A. niger*, *A. fumigatus*, and *A. nidulans*), the Xception software was trained with images taken with a stereo microscope. Original colony photographs of a total of 8995 colonies from seven species were used for training. From these photos, 17,142 images showing conidiophore and colony morphologies of each species were obtained and introduced to the software. The Xception software demonstrated a classification success rate of 99.8% (21).

Artificial Intelligence for Parasitology

Parasites, with a more advanced structure compared to other microorganisms, are invertebrate animals that can cause diseases in humans and other animals. They are often considered tropical and, therefore, have not been of great importance to physicians in colder and more developed countries. However, with an increasing number of tourists, Peace Corps volunteers, businessmen, and others visiting exotic regions of the world and staying for extended periods, these individuals are at risk for infections that are rare in developed countries. Therefore, the diagnosis of parasites is as crucial as other diseases.

Parasites are classified into four classes: Protozoa, Animalia, Fungi, and Stramenopila. They are categorized based on their nuclei and motile organs, morphologies, and reproduction methods, and distinctions are made according to these characteristics. Although the stool test (O&P) is a significant standard practice for detecting pathogens, it is costly in terms of time and labor (1).

Especially prevalent in Africa, malaria (malaria) caused by the *Plasmodium* genus is one of the most common parasitic diseases, with over 200 million cases annually. To facilitate the detection of this parasite, Liu et al. (22) developed software called AIDMAN. Using a more advanced version of the YOLOv4 algorithm called YOLOv5, AIDMAN accurately detected *Plasmodium* in thin blood smears with a high rate of 98.44% (22).

In a study analyzing the growth of pathogens and host defense behaviors, an AI software called HRMan (host response to microbe analysis) was used, which utilized convolutional neural networks (CNNs). HRMan 2.0 version evaluated the growth rates of intracellular infection agents such as *Toxoplasma gondii*, *Plasmodium spp*., and *Salmonella spp*. The algorithm also assisted in studying host-parasite interactions such as pathogen killing, extracellular behavior, and invasion rate (23).

Artificial intelligence-assisted telemedicine applications are also used in parasitology. With the AI-based application named TechCyte, remote diagnosis is possible. Stool samples on Kato-Katz slides were examined under a light microscope, photographed, and sent to the platform for diagnosis. This application also eliminates negative samples, thus increasing sensitivity (24).

Conclusion

In conclusion, as AI continues to advance in today's technology, it becomes more integrated into our lives. It enhances our quality of life by saving labor and time, ultimately raising our standards of living. However, alongside the positive outcomes enabled by AI, there are also challenges and limitations to be faced.

While AI systems offer accurate data and image analysis, the generated results are only beneficial when they are clinically meaningful and interpreted correctly.

Therefore, in the current state of AI, it should not be viewed as a definitive diagnostic tool. For instance, the Xception software's 86% accuracy in virus studies and 99.8% accuracy in fungal studies indicate that the same software may yield different results in different studies, highlighting that no single application should be considered an absolute safe method.

Additionally, with the increase in big data, resolving ethical issues related to unauthorized and non-consensual use of patient data requires the implementation of necessary regulations.

AI modules and algorithms should be made more accessible and user-friendly for everyone. However, due to the rapid data processing and special computing requirements of these algorithms, their usage and installation can be costly.

Despite facing certain limitations, it is evident that once these challenges are overcome through necessary regulations, AI will offer us a bright future in both clinical applications and our daily lives.

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