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Review Article

Artificial intelligence (AI) and medical microbiology: A narrative review

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ABSTRACT

Artificial Intelligence (AI) has transformed numerous domains, including the discipline of medical microbiology. Artificial intelligence is currently being used to assist in clinical decision-making and the monitoring of diseases, with the possibility of being used for genomic information and extensive digital datasets. Through the utilization of advanced algorithms, machine learning (ML), and deep learning (DL) methods, artificial intelligence (AI) can improve disease diagnoses, forecast outbreaks, and customize medical treatments. Moreover, AI is revolutionizing the field of medical and pharmaceutical microbiology, specifically in the areas of pathogen identification, development of point-of-care diagnostics, and drug discovery. Machine learning (ML) is of great use for image analysis since it improves the effectiveness and accuracy of clinical microbiology practice. Despite these developments, it is imperative to tackle issues related to the accuracy of data and limitations of algorithms. Additionally, it is crucial to focus on creating AI models that can be easily understood and interpreted. This review examines the present uses, advantages, and obstacles of AI in medical microbiology, emphasizing its revolutionary impact on enhancing healthcare results.

1. Introduction

Earlier the detection and investigation of infections required time-consuming methods such as culture techniques, microscopy, and biochemical testing. Although these conventional approaches serve as the basis, they frequently encounter constraints such as lengthy processes, the requirement for specialized expertise, delay in treatment, cross-contamination and false-positive cultures, lack of real-time epidemiological surveillance, lack of standardized procedures and quality measures the possibility of human errors.

The incorporation of artificial intelligence (AI) into medical microbiology tackles these difficulties by automating and can revolutionize microbiological diagnostics by providing faster, more accurate, and efficient ways that improve patient outcomes and address the challenges associated with traditional diagnostic approaches.[1]

The implementation of Matrix-assisted laser desorption/ionization-time of flight mass spectrometry (MALDI-TOF MS) coupled with AI has greatly expedited and enhanced the precision of pathogen identification in the field of clinical microbiology.[2] Currently, this method is both speedy and accurate, making it a cost-effective way to identify cultured bacteria and fungus in clinical microbiology. It performs at least as well as, if not better than, standard biochemical identification methods. This technology has emerged as the favoured approach for identifying anaerobic bacteria and mycobacteria, although it does have certain constraints when it comes to distinguishing closely similar species.[3]

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Artificial intelligence (AI), with its capacity to analyse extensive information and detect patterns, presents new opportunities for microbiological diagnoses and research. AI has the potential to address public health challenges, such as the management of infectious diseases and sepsis, by assisting in the diagnosis, prognosis, and personalized treatment strategies of microbiology. Additionally, AI's application in the prevention and control of infections is noteworthy, as it can analyse extensive health datasets, thereby facilitating the identification of outbreaks and the development of effective infection control strategies.[4]

The objective of this paper is to investigate the multifaceted importance of AI in medical microbiology, with a particular emphasis on its impact on clinical applications and research. We will examine how AI is not only transforming existing methodologies but also facilitating the development of discoveries and innovations in the field of microbiology, thereby making a substantial contribution to the progress of public health and healthcare. Insights into the current state of the art, challenges, and prospects of this interdisciplinary alliance will be provided by this study.

2. Methodology

The current literature review employed various reputable sources, including PubMed, Google Scholar, Scopus, and Web of Science, to identify relevant studies on the application of artificial intelligence in the domain of medical microbiology. The search criteria included terms such as "AI in medical microbiology", "ML in medical microbiology", "DL in medical microbiology", "AI and AMR", "AI and infection control", and "AI and medical diagnostics". The inclusion criteria comprised peer-reviewed papers published between January 2010 and January 2024, written exclusively in the English language. The exclusion criteria comprised non-peer-reviewed articles, editorials, and publications that did not specifically address AI in medical microbiology.

The search methodology involved doing preliminary keyword searches, which were subsequently enhanced by employing inclusion and exclusion criteria. An evaluation was conducted to determine the significance of titles and abstracts, and complete publications were acquired for further research. The data about the particular AI technology, its application, benefits, and limitations were retrieved and categorized. The methodological quality of the research was assessed using a predefined checklist, and the results have been presented through narrative synthesis. This method provided a comprehensive examination of the current state of circumstances and identified trends and gaps in the use of artificial intelligence in the specialty of medical microbiology.

3. Discussion

3.1. Definitions

3.1.1. Machine learning (ML)

Machine learning is a component of AI that allows systems to acquire knowledge and improve processes without the need for explicit programming. ML enables computers to acquire knowledge from data, statistics, and iterative experimentation, thereby modifying their actions based on past experiences.

To simplify, Machine Learning is an area of research that enables computers to acquire knowledge and make predictions without explicit human instructions.

3.1.2. Deep learning (DL)

Deep learning subset of machine learning, uses neural networks with multiple layers (deep architectures). These networks learn hierarchical representations from data, capturing intricate patterns and features.

3.2. The mechanism of ML

1. Data collection and training in machine learning: This involves the initial step of gathering various types of data, such as numerical values, textual information, images, and so on. The data, commonly referred to as "training data," acts as the fundamental basis for instructing the ML algorithm.
2. During the training process, the algorithm acquires knowledge of patterns, relationships, and distinctive characteristics from the data. It involves instructing a model to identify apples by exposing them to different images of apples.
3. Algorithm development: Data scientists construct machine learning algorithms. The choice of algorithm is contingent upon the particular task and data being processed. Algorithms can range from straightforward, such as linear regression, to intricate, such as neural networks.
4. Forecasting and Generalization: After being trained, the machine learning algorithm can make predictions on novel, unobserved data. The algorithm extrapolates from the training data to effectively address real-world situations. For instance, it anticipates whether a received image corresponds to an apple or not.

3.3. Types of machine learning

1. Supervised learning: Uses labelled data (examples with clear descriptions) to make accurate predictions. Think of it as teaching with labels.
2. Unsupervised learning: Works with unlabelled data. The algorithm groups or categorizes data based on similarities, patterns, and differences.

3. Reinforcement learning: The program learns by interacting with an environment, and receiving rewards or penalties.

3.4. Real-world examples

1. Product recommendations: ML powers personalized recommendations on e-commerce sites (like suggesting products you might like).
2. Movie suggestions: Netflix uses ML to recommend movies based on your viewing history.
3. Healthcare: ML aids in disease prediction, diagnosis, and treatment.[5]

3.5. Applications of AI in medical microbiology

AI and ML are transforming various aspects of microbiology, including clinical diagnostics, drug and vaccine discovery, and public health management. Key areas of AI application in microbiology include enhanced pathogen identification, advancements in point-of-care diagnostics, and the development of new antimicrobials to tackle resistant strains.

3.5.1. Diagnostic microbiology

3.5.1.1. Image analysis. Machine learning-based image analysis has the potential to revolutionize microscopy and agar plate inspection in diagnostic laboratories, radically changing their workflows.[6] Clinical microbiology data sets like genomic information, metagenomic findings, mass spectra, and digital images are amenable to AI diagnostics. Clinical microbiologists need to study, develop, and implement AI and computer vision to improve clinical microbiology.[7] In the future, it is anticipated that AI algorithms will be employed to pre-screen and pre-classify image data. This will enhance productivity and facilitate more precise diagnoses by fostering collaboration between the AI system and the microbiologist.[8]

A recent study in 2021 successfully developed and validated an AI-based digital pathology system to screen for acid-fast bacilli (AFB) in tissue samples, which proved to be more sensitive, accurate, time-efficient, and easier to use than manual microscopy or whole-slide image (WSI) examination. The deep learning algorithm showed strong performance, with an AUC of 0.960 at the image patch level. AI-assisted reviews identified more AFBs, had higher sensitivity (64.8%), specificity (95.1%) and negative predictive value (83.6%), and better matched original diagnoses compared to manual methods.[9]

AI has applications in laboratory medicine for making operational decisions and automating or enhancing human-based workflows. These include instrument automation, error detection, forecasting, result interpretation, test utilization, genomics, and image analysis. In the future, AI will become a routine tool in clinical laboratories. Laboratory professionals need to comprehend the potential role of AI in this emerging field and the various opportunities it presents for AI technologies.[10]

AI and human collaboration are expected to improve efficiency, quality, and patient care in clinical microbiology laboratory practice in the future.[11] Image analysis with AI currently only augments human effort and is not a replacement for human expertise.[12]

Convolutional neural networks (CNNs) are commonly used in computer-aided diagnosis (CADx) for malaria detection. The software greatly improves the precision of detecting cells infected with malaria.[13] Advanced techniques have improved the detection of parasites in faecal samples, surpassing the sensitivity of traditional human slide examination.[14]

3.5.1.2. Automated culture analysis. AI algorithms can analyse growth patterns in culture media to identify bacterial species. Automated systems equipped with AI can monitor cultures in real time, providing quicker results compared to traditional methods. These algorithms are trained to identify precise patterns or genetic markers linked to different pathogens.

Machine learning algorithms, specifically “Extreme Gradient Boosting” outperformed a heuristic model in reducing the workload of urine sample culture while maintaining a classification sensitivity of over 95%. The optimal solution was to use three independent Extreme Gradient Boosting algorithms to classify urine samples from pregnant patients, children, and all other patients, which resulted in a 41% relative workload reduction and 95% sensitivity for each subgroup. The heuristic model based on the machine learning findings was successfully implemented in the diagnostic laboratory, leading to considerable time and cost savings without compromising diagnostic performance.[15]

In 2023, Dr. Harris published a review that explores using machine learning models in the future to rapidly provide diagnostic outcomes for urinary tract infections. The analysis focused on research that uses machine learning techniques to enhance the detection of urinary tract infections (UTIs), minimize the usage of antibiotics, provide treatment guidance without relying on urine culture, and decrease the clinical workload and unnecessary hospital visits.[16]

Artificial intelligence (AI) has a diverse role in healthcare, including the use of machine learning (ML), deep learning, and natural language processing (NLP) to aid in the identification of microbial infections. It is highly efficient in analysing structured data from hospital labs and oncology radiography.[17] Natural Language Processing (NLP) simplifies the process of creating and maintaining Electronic Medical Records (EMRs), allowing for the identification of different diseases by analysing speech and text.[18]

AI applications in culture interpretation entail the creation of intricate algorithms for identifying cultures and improving the efficiency of analysing microbial cultures.[7] Automated systems such as the automated plate assessment system (APAS) Independence and PhenoMATRIX have improved the examination of cultures in urine samples and the diagnosis of Methicillin-resistant Staphylococcus aureus (MRSA).[19] Artificial intelligence (AI) is capable of forecasting the patterns of antimicrobial susceptibility, which helps in promptly identifying and treating drug-resistant infections.Kiestra Total Laboratory Automation (TLA) and WASP Lab are prominent instances of artificial intelligence (AI) being included in extensive laboratory procedures.[20]

In diagnosing sexually transmitted infections like trichomoniasis, ML algorithms distinguish between positive and negative cases using routine test results, such as urinalysis. This approach is particularly beneficial in resource-limited settings.[21]

3.5.1.3. Molecular diagnostics. AI enhances the interpretation of molecular diagnostic tests, such as Polymerase Chain Reaction (PCR) and Next-Generation Sequencing (NGS). Machine learning algorithms can process the complex data generated by these techniques, leading to faster and more accurate pathogen identification and resistance profiling.

The introduction of MALDI-TOF mass spectrometry has significantly accelerated and improved the specificity of pathogen identification in clinical microbiology. Rapid molecular tests can further reduce the time to identify pathogens and detect key resistance determinants. The benefits of these technical improvements only translate to patient benefit if the results are rapidly communicated and interpreted by clinicians, highlighting the importance of collaboration between the microbiology lab and antimicrobial stewardship teams.[2]

3.5.2. Discovery of drugs and predicting antimicrobial resistance (AMR)

Artificial intelligence facilitates the identification of possible therapeutic targets through the analysis of microbial genomes, proteomes, and metabolic pathways. This enhances the drug development process by forecasting the affinities for the binding of compounds to microbial targets, hence speeding the selection of candidate medications for experimental validation.[22]

AI has a substantial impact on forecasting the pharmacokinetic and pharmacodynamic properties of medicines. AI-powered modelling minimizes adverse reactions, optimizes dosage levels, and guarantees the safety, efficacy, and compatibility of clinical development.[23]

Artificial intelligence utilizes information on permitted pharmaceuticals and their modes of action to identify licensed treatments that can be repurposed for the treatment of microbiological diseases. This strategy can be time-saving by circumventing protracted drug development procedures.[24]

AI can predict antimicrobial resistance patterns by analysing the genetic sequences of pathogens. Machine learning models trained on large datasets of genomic information can identify mutations associated with resistance, aiding in the selection of appropriate therapies and reducing the spread of resistant strains.

AI, especially deep learning and machine learning, is being used to tackle challenges in the antimicrobial resistance (AMR) domain by leveraging large amounts of data. AI has opened new pathways in AMR, such as reducing diagnostic time from days to hours and discovering new AMR genes and mutations.[25]

Another study examined how machine learning models are facilitating the use of sequence-based diagnostics to forecast antibiotic resistances using genome sequencing data.[26]

Popa et al. in their study summarised that deep learning and other AI techniques have been used to 1) Shorten the preclinical phase of drug development by rapidly generating and evaluating many new antibiotic molecules; 2) Repurpose existing drugs, such as discovering new uses for propranolol; 3) Discover new antimicrobial peptides using DL variations and by combining DL with other methods; and 4) Improve the accuracy of differentiating between antibiotic-resistant and antibiotic-susceptible bacteria, which can assist clinical decision-making.[27]

3.5.3. Epidemiology and outbreak prediction

AI systems can analyse epidemiological data to predict outbreaks and track the spread of infectious diseases. Machine learning models can integrate data from various sources, including social media, weather patterns, and travel records, to forecast disease hotspots and inform public health interventions. AI is also being used in epidemiology, microbial ecology, and forensic microbiology to decipher complex microbial interactions and forecast disease outbreaks.[18]

AI can analyse clinical and epidemiological data in real time to assist with contact tracking and evaluate the efficacy of containment strategies. The utilization of AI technology in microbial detection is transforming the process of identifying and controlling epidemics, leading to the protection of lives and a decrease in the impact of infectious illnesses on global health.

Tools like the Cowin App, Sehaty App, and Ebola Care app provide healthcare personnel with critical insights for treatment decisions by analysing clinical symptoms and laboratory data.[28]

Table 1: The benefits and challenges in the implementation of AI[29]

Benefits of AI	Challenges of AI
Improved Accuracy and Speed- AI algorithms can process and analyze data faster than traditional methods, leading to quicker and more accurate diagnoses **Enhanced Data Integration**- AI can integrate and analyze data from multiple sources, providing a comprehensive view of patient health and disease trends. **Early Detection and Prevention** - AI's predictive capabilities can enable early detection of outbreaks and antimicrobial resistance, allowing for timely interventions. **Cost-Effectiveness**- Automating diagnostic and analytical processes with AI can reduce labor costs and resource utilization, making healthcare more cost-effective. **Personalized Medicine**- AI can facilitate personalized treatment plans by integrating patient data, including genetic, clinical, and lifestyle information. Machine learning models can predict patient outcomes and suggest tailored therapies, improving the efficacy of treatments for infectious diseases. **Increased access to healthcare**- Deploying AI-powered diagnostics remotely enhances healthcare accessibility, enabling underserved populations and overcoming geographical obstacles. Artificial intelligence is very beneficial during periods of epidemics. **Minimizes human errors**- AI reduces human errors, leading to consistent and verifiable results, hence enhancing the safety and success of therapies.	**Cost-** Purchasing and implementing AI technologies can be expensive, potentially creating challenges for smaller healthcare facilities and those with limited financial resources. **Data Quality and Quantity**- AI models necessitate substantial quantities of meticulously curated data for training. The accuracy and usefulness of these models can be limited by inconsistent or inadequate data. **Interpretability-** AI systems, especially deep learning models, are commonly perceived as "black boxes" due to their non-transparent decision-making processes. The absence of openness might impede trust and acceptability among healthcare providers. **Ethical and Legal Considerations**- The use of AI in healthcare raises ethical and legal issues, including patient privacy, data security, and the potential for algorithmic bias. Ensuring that AI systems are ethical and fair is crucial for their widespread adoption. **Integration with Existing Systems**- Integrating AI tools with existing healthcare infrastructure can be challenging. Compatibility issues, the need for specialized training, and resistance to change are potential barriers. **Training** - Skilled professionals are crucial for overseeing the functioning of artificial intelligence and evaluating outcomes. **Fear of replacement**- Healthcare professionals are hesitant to embrace AI technology because they are concerned about the possibility of losing their jobs. **Lack of resources**- The absence of internet connectivity in places with low resources may impede the implementation and maintenance of artificial intelligence systems.

3.5.4. Infection prevention and control measures

Artificial intelligence (AI) is transforming the surveillance of healthcare-associated infections (HAIs) and improving infection prevention and control (IPC). The application of analysing complicated datasets from electronic healthcare records (EHRs) is essential for monitoring infection trends and evaluating intervention options.[30] The use of AI in diagnosing illnesses with implications for infection prevention and control (IPC) is demonstrated by its application in tuberculosis diagnosis by the utilization of deep learning on chest radiography.[31] Laboratories utilize AI-enhanced microscopy and ML algorithms to achieve swift diagnosis and precise antibiotic treatment.[32]

Although AI has the potential to bring about significant changes, the difficulties in obtaining datasets of high quality for the creation of models continue to exist. However, AI has the potential for enhanced effectiveness in monitoring infections and a substantial influence on the administration of public health and patient care policies.[33]

3.5.5. Patient management

The significant role of AI in early warning systems for sepsis is demonstrated by models that forecast the occurrence of sepsis ahead of time, surpassing conventional scoring methods.[34] The models have been broadened to incorporate regular clinical factors, improving the practicality of sepsis prediction in different environments.[35] Artificial intelligence (AI) has enhanced the detection of sepsis by utilizing screening methods that rely on big data and machine learning. These techniques incorporate unstructured textual data to improve accuracy.[36]

Empirical research validates the efficacy of artificial intelligence in the management of sepsis, establishing a correlation between early warning systems and decreased fatality rates as well as shorter durations of hospitalization.[37] Artificial intelligence (AI) also assists in the process of sepsis subtyping, which involves categorizing different phenotypes with different clinical characteristics.[38] AI models are used in pathogen identification and antimicrobial susceptibility testing to quickly detect common bacteria and fungi. This helps optimize empirical antibiotic therapy.[39] AI models are used to guide fluid resuscitation and management during sepsis treatment. These models may predict post-resuscitation urine output and fluid responsiveness.[40] Causal inference frameworks are used to evaluate therapy effects, which in turn help in providing individualized medical care.

AI models have greatly enhanced the accuracy of predicting in-hospital mortality rates and have also effectively reduced the length of hospital stays in sepsis prognosis.[41] Nevertheless, additional investigation is required to authenticate these models and incorporate them into therapeutic applications.(Table 1)

4. Limitations of the Study

Although this article reviewed the important uses of AI in medical diagnostics, however more possible applications could not be included due to the time constraint and word limit.

5. Future Directions

The future of AI in medical microbiology is promising, with ongoing research aimed at overcoming current challenges. Key areas of focus include:

1. Enhanced data sharing: Offering secure and regulated mechanisms for sharing data to enhance the training and validation of AI models.
2. Explainable AI: Developing AI models that offer transparent and easily comprehended data to establish confidence among healthcare practitioners.
3. Collaborative research: Facilitating partnerships among microbiologists, data scientists, and clinicians to create solutions using AI that effectively address clinical requirements.
4. Regulatory frameworks: Implementing strong regulatory frameworks that will ensure the safety and ethical use of AI in the healthcare sector.

6. Conclusion

The application of artificial intelligence has the potential to revolutionize medical microbiology by improving diagnosis accuracy, anticipating outbreaks, and personalizing treatment techniques. The implementation of AI into clinical practice holds the potential to improve patient outcomes and further advance our knowledge of infectious diseases, although there are obstacles to overcome beforehand. Continued research, collaboration, and ethical considerations will be key to realizing the full potential of AI in this field.

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8. Conflicts of Interest

The author declares no conflicts of interest.

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