International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

AI & ML Applications in Microbiology: A Comprehensive Review

[1]Avin Joe Boby, [2]Adinath Praveen, [3]Christy Saji, [4]Noel Jacob Antony*

[1,2,3,4]StudentSchool of Engineering and Technology, CHRIST (Deemed To Be University), Bangalore 560060, India
avin.joe@btech.christuniversity.in, adinath.praveen@btech.christuniversity.in, christy.saji@btech.christuniversity.in
noel.jacob@btech.christuniversity.in

A B S T R A C T

Recent discoveries have emerged in microbiology due to integrating Artificial Intelligence (AI) and Machine Learning (ML) techniques. This study explores the applications, methods, and possible futures of AI and machine learning in microbiology. They have profoundly influenced different fields of microbiology, such as disease diagnosis, drug detection, bioprocess optimisation, and microbial genetics. Implementing AI and ML in microbiology has improved antimicrobial resistance.

Clinical biology has had a positive impact with the help of AI and ML in microbiology, which are used to detect various diseases. Bioinformatics helps to form a bridge between the sequence data and the biological functioning of an organism. Analysing the human microbiome with the help of microbiology has impacted the estimation of postmortem intervals. AI and ML algorithms are essential in detecting sickness by recognising patterns and anomalies in microbiological data. Furthermore, interdisciplinary integration using AI and ML would help drastically improve the integration in microbiology.

Keywords: Artificial Intelligence (AI), Machine Learning (ML), Microbiology, Bioinformatics, Microbiome Analyzation

1. Introduction

1.1 What is Microbiology?

Microbiology studies microscopic creatures like bacteria, viruses, fungi, and protozoa. It investigates their structure, genetics, behaviour, and interactions with their surroundings. Microbiology is essential in health, agriculture, and biotechnology because it helps with disease detection, vaccine development, and food safety. Understanding these microbes helps to fight diseases, improve agricultural techniques, and advance biotechnological technologies for a healthier, more sustainable planet.

1.1.1 History of Microbiology

The study of tiny life forms started in the 1600s with Antonie van Leeuwenhoek's work using microscopes. In the 1800s, Louis Pasteur and Robert Koch built up the idea that germs cause disease and found some of those germs. Alexander Fleming's work on drugs like penicillin changed health care in the mid-1900s. New steps in tiny life science and virus study improved our knowledge of how these tiny life forms work and cause disease. In the past years, the study of tiny life has grown to look at nature's tiny life groups and how they fight against drugs. These significant steps have taught us more about the many types of tiny life and their role in our well-being and the world, pushing forward good changes in healing, farming, and making things.

1.1.2 Scope of Microbiology

Microbiology, as a scientific field, is the study of microorganisms such as bacteria, viruses, fungus, protozoa, and algae, as well as their interactions with the environment and other creatures. Its scope encompasses various subjects, including medicine, agriculture, and environmental research. The primary goal of medical microbiology is to diagnose, cure, and prevent infectious diseases, as well as to investigate host-microbe interactions and create vaccines and medications. Through its vast scope of research, microbiology contributes significantly to advancing scientific knowledge, resolving global concerns, and improving human health, environmental sustainability, and industrial processes.

1.2 Implementation of AI & ML in Microbiology

AI and ML transform microbiology by analysing molecular structures and genomic data to predict drug candidates and antimicrobial resistance patterns, revolutionising drug discovery and personalised medicine approaches. These technologies also decipher microbial diversity and ecological interactions from metagenomic data, aiding in understanding host-microbiome relationships and ecosystem dynamics.

1.2.1 Drug Discovery

Drug discovery using microbiology involves screening microorganisms and their products for potential therapeutic compounds. This method involves searching natural sources, such as bacteria and fungi, to discover bioactive compounds. High-throughput screening automates testing extensive collections of chemicals against microbes, facilitating the rapid identification of potential compounds. Phenotypic screening observes the effects of chemicals on microbial growth or disease-causing ability, often resulting in the discovery of new antibiotics and antifungals. Promising compounds undergo chemical refinement and development to prepare them for clinical trials, where their efficacy and safety are evaluated before being approved for patient use by regulators.

1.2.2 Phenotypic Screening

In microbiology, phenotypic screening tests how microorganisms react to chemical or environmental changes by examining their visible features and behaviours. This method doesn't rely on knowing specific molecular targets, which makes it great for finding compounds that work in new ways or affect a wide range of organisms. Phenotypic tests can reveal changes in microbial growth, appearance, metabolism, or ability to cause disease. These tests are often used in developing new antimicrobial drugs to find promising compounds that can be further improved and used in clinical settings. There are 10^5 to 10^9 distinct microbial species or more [1,2], and only about 11,000 have been described and named [3,4]. Furthermore, phenotypic screening can identify prospective drug targets, illuminate microbial processes, and promote the development of more tailored therapeutic intervention strategies.

1.2.3 Disease Diagnosis and Prediction

AI and machine learning are changing disease detection and prediction in microbiology. They analyse microbial genetic data very accurately. They can classify infectious diseases and predict antibiotic resistance patterns. Also, they can find new infections by spotting new microbial sequences or genetic changes. This helps healthcare providers and public health officials respond to possible disease outbreaks early. Using AI and machine learning in disease diagnosis and prediction improves accuracy and treatment and helps us monitor and control diseases.

1.2.4 High-Throughput Screening (HTS)

High-throughput screening (HTS) in tiny life study is a quick, auto way of checking many chems or gene bits against tiny life. It lets people quickly look at the work of lots to loads of chems, making drug or probe finding faster. In the Tiny Life Study, HTS tests look for stuff with the proper life effects by checking tiny life growth stops, how they eat, or other clear reactions. These tests are vital for making germ-killing drugs because they let people look through many chem groups to spot the main themes that fight germs, mould, and viruses. Implementation in pharmaceutical and agrochemical companies has been accompanied by numerous reports and communications discussing biochemical and cellular screens[5]. It allows researchers to quickly examine the activity of hundreds to millions of chemicals, speeding up the discovery of prospective medication candidates or molecular probes. HTS tests frequently detect substances with intended biological effects in microbiology by evaluating microbial growth inhibition, metabolic activity, or other phenotypic responses. These assays are critical for antimicrobial drug development because they enable the screening of different chemical libraries to find lead compounds with antimicrobial activity against bacteria, fungi, and viruses. Furthermore, HTS may be utilised to investigate microbial pathways, find pharmacological targets, and understand the mechanisms of action for new medicinal medicines.

1.2.5 Bioprocess Optimization

A biological process is a complex cell and environment interaction [6]. The application of AI/ML methodologies is revolutionising bioprocess optimisation through the autonomous refinement of bioremediation, bioproduction, and microbial fermentation processes. Requirements like temperature, pH, and nutrient concentrations are expertly controlled by ML algorithms, which dynamically adjust to variations and guarantee ideal microbial growth and metabolism circumstances. AI/ML models detect complex patterns and correlations by continuously observing and evaluating process data. This allows for the predictive modification of process parameters to maximise product yield and quality and reduce waste production. These algorithms can independently detect and take remedial action in response to deviations from ideal circumstances, streamlining operations and increasing process efficiency. To maximise efficiency and save time and costs, AI/ML-driven bioprocess optimisation also dramatically lowers manual intervention requirements. This strategy promotes sustainability by reducing resource consumption and environmental impact, consistent with green biotechnology and circular economy strategies. In conclusion, microbial-based enterprises undergo a revolution due to the integration of AI/ML in bioprocess optimisation, which opens the door to hitherto unheard-of levels of productivity, sustainability, and efficiency.

1.3 Challenges and Future Directions

Even though AI and ML can revolutionise microbiology, several obstacles must be overcome to realise their full potential. These include the necessity for high-quality training data, the interpretability of machine learning models, ethical considerations in data utilisation, and the integration of domain knowledge with computational methodologies. Furthermore, future research approaches in AI and ML for microbiology could emphasise interdisciplinary cooperation, creating user-friendly software tools, and deploying solid validation procedures.

2. Applications of AI and ML in Microbiology

Artificial intelligence (AI) and machine learning (ML) have various applications in microbiology, revolutionising the field in multiple ways. When applied to clinical microbiology, AI can make us more efficient and accurate and even draw new conclusions from data generated in our laboratories. This is great as these capabilities can be implemented to improve patient care. AI is extensively used for image analysis, including Gram stains, ova and parasite exams, and digital plate readings of bacterial cultures [7].

In clinical microbiology, Respiratory Gram stains could be interpreted through automated quantification and discrimination of inflammatory, epithelial, and bacterial cell morphologies. For example, using Artificial Intelligence, an image could be construed as having a 90% probability of Gram-positive cocci in clusters and a 10% probability of Gram-positive cocci in chains [8].

AI models can classify microorganisms based on their genetic sequences or phenotypic characteristics. Tuberculosis is a disease caused by Mycobacterium tuberculosis. It is imperative to detect cases of TB as early as possible because if left untreated, it could be fatal. Computer-aided detection (CAD) is the most widely used artificial intelligence tool that analyses the patient's chest X-rays and determines if the patient is affected by TB. This process reduces the workload of the radiologists, and ultimately, it speeds up the screening process [9]. In AI-based drug improvement, the first step is the ML of a primary image, then processing it and sorting the druggable molecules and the targets [10].

Bioinformatics forms the bridge between the sequence data and the biological functioning of an organism(s). Artificial Intelligence plays a massive role in bioinformatics by leveraging advanced algorithms, which can help analyse vast amounts of biological data much more efficiently. Using Machine Learning algorithms, AI can predict optimal outputs based on past data records, providing valuable insights into disease causation, evolutionary patterns, drug customisation, protein structure prediction, and DNA sequencing [11]. The ability of AI and ML to simulate human intelligence can be beneficial in accelerating drug discovery and addressing complex clinical challenges [12].

Antimicrobial Resistance (AMR) is a global health crisis that poses a significant threat to modern medicine. Thus, rapid and accurate AMR diagnostics are needed. However, traditional Antimicrobial Susceptibility Testing is time-consuming and viable only for cultivable bacteria [13]. AI, mainly machine learning, is increasingly being used to address the crisis of AMR by predicting the resistance of different antibiotics in microbes based on gene content and genome composition. ML can provide prevention strategies and guide treatment methods by analysing hundreds and thousands of datasets on gene content and genome composition [14].

Human microbiome analysis studies microbial communities found in and on the human body. Microbiome analysis has emerged as a promising postmortem interval (PMI) estimation avenue. AI advancements have helped researchers enhance their understanding of postmortem microbial communities, which enabled them to make much more accurate predictions. AI facilitates the analysis of large datasets and develops models based on them [15].

3. Conclusion

In conclusion, integrating artificial intelligence (AI) and machine learning (ML) into the field has changed the game in microbiology, which offers powerful tools to analyse microbial data. AI and ML algorithms allow scientists to quickly comb through vast volumes of genetic and phenotypic data, from drug discovery to disease diagnosis. As a result, potential drug candidates are identified more quickly. In turn, it improves our understanding of microorganism behaviour and makes predicting disease outcomes easier.

AI and ML have also modified clinical practices to improve diagnostic capabilities while processes are streamlined. With the automatic interpretation of Gram stains or chest X-rays using AI-driven image analysis systems, clinicians can quickly evaluate whether a microbe like tuberculosis caused an infection. Machine learning algorithms also allow for rapid determination of antimicrobial resistance, thus aiding healthcare providers in developing personal treatment plans against the growing number of pathogenic strains resistant to drugs.

Thanks to the advancement of artificial intelligence and machine learning, the future holds great promise for microbiology. However, some challenges must also be addressed. Among these hurdles are the quality of data, model interpretability, and ethical issues concerning data use. Overcoming these barriers through interdisciplinary cooperation and rigorous validation processes is the key to unlocking AI and ML in microbiology to enhance global health outcomes.

References

1. Curtis TP, Sloan WT, Scannell JW: Estimating prokaryotic diversity and its limits. Proc Natl Acad Sci USA 2002, 99:10494-10499.

2. Bochner B: Global phenotypic characterisation of bacteria. FEMS Microbiol Rev 2009, 33:191-205.

3. Bochner B, Giovannetti L, Viti C: Important discoveries from analysing bacterial phenotypes. Mol Microbiol 2008, 70:274-280.

4. Euzeby JP: List of Prokaryotic Names with Standing in Nomenclature. 2011 http://www.bacterio.net.

5. Marie-Helene Beydon, Alain Fournier, Lionel Drugeault, Jerome Becquart: Microbiological High Throughput Screening: An Opportunity for the Lead Discovery Process. Journal Of Biomolecular Screening Volume 5, Number 1, 2000, 13

6. Panda, Tapobrata, P.S.R. Babu, J.A. Kumari, D.S. Rao, K. Theodore, K. Jagannandha Rao, S. Siva Kesava, A. Kapat, S.R. Nair, J. Sinha, R. Sreenivas, G. Lakshmi Prasanna, V. Venkata Dasu, M. Pazouki, P. Arthur Felse, G.S. Naidu, B. Gokul, S. Uma, K. Srividya, R. V. Muralidhar, K. Balamurugan, K. Chandrasekhar

7. Kenneth P. Smith, Hannah Wang, Thomas J.S. Durant, Blaine A. Mathison, Susan E. Sharp, James E. Kirby, S. Wesley Long, Daniel D. Rhoads, 'Applications of Artificial Intelligence in Clinical Microbiology Diagnostic Testing', Clinical Microbiology Newsletter, Volume 42, Issue 8, 2020, Pages 61-70, ISSN 0196-4399

8. Smith, Kenneth P., and James E. Kirby. "Image analysis and artificial intelligence in infectious disease diagnostics." Clinical Microbiology and Infection 26, no. 10 (2020): 1318-1323.

9. Acharya, Vasundhara, Gaurav Dhiman, Krishna Prakasha, Pranshu Bahadur, Ankit Choraria, M. Sushobhitha, J. Sowjanya et al. "AI-assisted tuberculosis detection and classification from chest X-rays using a deep learning normalization-free network model." Computational Intelligence and Neuroscience 2022 (2022).

10. Diab, R. (2023). Artificial intelligence and Medical Parasitology: Applications and perspectives. Parasitologists United Journal, 16(2), 91-93.

11. Majhi, Vinayak, and Sudip Paul. "Artificial Intelligence in Bioinformatics." Advances in Computational Intelligence Techniques (2020): 177-190.

12. Khadela, Avinash, et al. "AI, ML and other bioinformatics tools for preclinical and clinical development of drug products." Bioinformatics Tools for Pharmaceutical Drug Product Development (2023): 255-284.

13. Ren, Yunxiao, Trinad Chakraborty, Swapnil Doijad, Linda Falgenhauer, Jane Falgenhauer, Alexander Goesmann, Anne-Christin Hauschild, Oliver Schwengers, and Dominik Heider. "Prediction of antimicrobial resistance based on whole-genome sequencing and machine learning." Bioinformatics 38, no. 2 (2022): 325-334.

14. Kim, Jee In, Finlay Maguire, Kara K. Tsang, Theodore Gouliouris, Sharon J. Peacock, Tim A. McAllister, Andrew G. McArthur, and Robert G. Beiko. "Machine learning for antimicrobial resistance prediction: current practice, limitations, and clinical perspective." Clinical microbiology reviews 35, no. 3 (2022): e00179-21.

15. Wang, Z., Zhang, F., Wang, L., Yuan, H., Guan, D., & Zhao, R. (2022). Advances in artificial intelligence-based microbiome for PMI estimation. Frontiers in Microbiology, 13, 1034051.