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Role of Artificial Intelligence in AMR Prediction

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ABSTRACT

The rise of antimicrobial resistance (AMR) presents a significant health threat, resulting in around 1.27 million fatalities each year. The COVID-19 pandemic underscored the critical demand for groundbreaking antiviral therapies and reliable diagnostic methods. AI is crucial in forecasting AMR by examining bacterial whole genome sequences, enhancing treatment approaches and monitoring. Conventional approaches frequently miss new AMR factors, resulting in errors in detecting resistant strains. Machine learning (ML) has demonstrated its importance in predicting resistance trends, with instances of effective models reaching as high as 95% accuracy in estimating minimum inhibitory concentrations (MICs). AI supports applications in optimizing antibiotic utilization, forecasting infectious diseases, and improving drug development. Automated systems greatly enhance AMR genomic monitoring by providing actionable information for infection management. Although there have been notable advancements, obstacles persist in AI adoption, especially the absence of extensive clinical trials, which could hinder confidence in AI relative to traditional approaches. Tackling AMR necessitates collaborative actions within the One Health approach, combining strategies for human, animal, and environmental health. In conclusion, although AI and big data offer significant promise for addressing AMR, continuous research and improvement are necessary to address challenges and improve clinical applications.

Keywords: Artificial intelligence, Antimicrobial Resistance, Prediction, Machine learning, COVID-19

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Introduction

The rise and proliferation of antimicrobial resistance (AMR) represent a significant public health issue currently confronting the globe. AMR occurs when micro-organisms like bacteria, viruses, fungi, and parasites develop resistance to medicines that were previously effective in managing infections caused by these micro-organisms. Worldwide, 1.27 million fatalities happen annually as a result of AMR. Recently, new and resurfacing viruses like the COVID-19 pandemic, resulting from SARS-CoV-2, have demonstrated the necessity of ongoing research and innovation in creating new antiviral treatments and vaccines to combat such occurrences. These incidents have compelled the authorities to implement required measures to address these issues and suggest suitable diagnostic techniques. These methods will enable the implementation of suitable measures to reduce the risk of AMR by utilizing precautions and correct antibiotics [1].

Predicting AMR from bacterial whole genome sequencing can expedite effective treatment, enhance surveillance, and decrease dependence on slow culture-based susceptibility testing. Nevertheless, numerous genomic AMR workflows continue to rely on curated catalogs of genes and mutations, which may overlook new mechanisms, differ in coverage among species, and seldom offer calibrated uncertainty. We introduce a phenotype-first approach that develops models to forecast resistant, intermediate, or susceptible results directly from genomic sequences utilizing open databases [2]. Key factors contributing to the rise of AMR as a worldwide health threat include unregulated access to antimicrobials, excessive antibiotic use in both human and animal health, inadequate infection control and insufficient rapid diagnostics. Consequently, global health security is at risk as AMR has reduced the effectiveness of treating common infections, jeopardizing years of advancements in medicine. The purpose of this article is to elaborate on the role of artificial intelligence in combating antimicrobial resistance [3].

Recognition of Antimicrobial Resistance

Prior to employing AI for identifying AMR determinants, AMR was assessed by comparing sequences to databases through bioinformatics or by conducting antimicrobial susceptibility tests (AST). By employing these techniques, many actual AMR determinants with quite different sequences from those currently identified as AMR would be misclassified as non-AMR (false negatives). Additionally, the process of culturing bacteria in AST takes a considerable amount of time, and specific bacteria [4].

Difficulties in Addressing Antimicrobial Resistance

AMR is a growing worldwide health emergency that compromises the effectiveness of contemporary medicine and jeopardizes advancements in managing infectious diseases. Even with scientific progress, worldwide initiatives to manage AMR still encounter significant challenges due to biological, economic, behavioral, environmental, and systemic issues. The continuity and growth of AMR highlight fundamental issues that necessitate creative, interdisciplinary approaches within the One Health framework, encompassing human, animal, and environmental health [5].

Role of AI in AMR Forecasting:

AI has been utilized in multiple areas, including designing, discovering, predicting, monitoring, and researching for AMR management. It has the ability to develop customized treatment strategies tailored to individual patients' genetic features and disease specifics. Recent research indicates that AI has been utilized to create new antibiotics and produce synergies in drug combinations. AI tools are frequently employed in the creation of novel antibiotics and investigating synergistic antibiotic pairings to combat AMR through predictive AMR models and the strategic use of antibiotics [6].

Role of ML:

ML has been widely utilized in the advancement of research on antimicrobial resistance. Macesic and associates' research shows that machine learning approaches can forecast and recognize resistant strains using genotypic and phenotypic information while enhancing treatment strategies and refining clinical antimicrobial susceptibility testing for multidrug-resistant (MDR) infections. Nguyen et al. employed a large collection of non-typhoidal Salmonella genomic data and associated antibiotic susceptibility profiles gathered from initiatives like the National Antimicrobial Resistance Monitoring System (NARMS) to create ML techniques that forecast minimum inhibitory concentrations (MICs) within a ±1 2-fold dilution range, reaching an overall model accuracy of 95%. These models aim to forecast MIC values to direct response strategies during outbreaks and assist in antibiotic usage choices. ML techniques have been used to uncover microbial resistance mechanisms to antimicrobials by examining genomic data. These studies concentrate on the assessment of patient information, diagnostics, treatments, and the prevention of resistance emergence in clinical environments [7].

Applications of AI include predicting infectious diseases in children, optimizing antibiotic usage, forecasting resistance patterns, and assisting in the prediction of protein structures and drug development [8].AI-driven systems, such as deep learning, machine learning, and reinforcement learning, utilized in AMR monitoring and management are essential for deciphering, annotating, and identifying therapeutic targets that confer resistance, ensuring high throughput and precision. Artificial Intelligence acts as a flexible tool that enables understanding the structural and regulatory intricacies of resistance proteins [3].

AI/ML and sophisticated computational methods are progressively aiding in the genomic monitoring of antimicrobial-resistant outbreak clones within healthcare environments. Their primary value is in enhancing, expanding, and analyzing WGS-based surveillance instead of substituting it. Through automation, prioritization, swift screening, forecasting, transmission modeling, and incorporation of IPC-related metadata, these methods can facilitate the conversion of genomic surveillance into more practical infection-control insights [9]. A key drawback of ML models is their Black Box characteristic, especially since DL algorithms frequently face criticism for being difficult to interpret. As a result, healthcare professionals might find it difficult to rely on the forecasts generated by these models, which is crucial for making well-informed treatment choices [10]. Data shortage and Standardization continue to be a significant challenge, as high-quality, and thoroughly annotated datasets are critical for dependable model development in AMR biosensing studies. Nonetheless, data produced by biosensors are frequently restricted, poorly distributed. Generalizability and Overfitting is another issue. The absence of clarity and openness—the infamous “black box” issue—can additionally weaken practitioner confidence, restricting implementation in healthcare systems [11].

The Significance of Big Data in Monitoring Healthcare

Big data revolutionized healthcare monitoring by enhancing the ability to analyze extensive health information, enabling medical professionals to make timely decisions and track diseases more effectively for improved public health outcomes. By merging data from the Payment Services System with social media platforms and wearable technology, public health officials gain immediate access to disease outbreaks. The incorporation of artificial intelligence in healthcare enhances efficiency in diagnostics and treatment planning due to its application [10]. The other Al models used in antimicrobial stewardship are Decision Trees and Random Forests, Boosted Models (examples include Extreme Gradient Boosting), Support Vector Machines and Neural Networks [12].

Applications

In recent years, artificial intelligence (AI) has shown significant proficiency in the area of AMR management. For instance, applications of artificial intelligence that utilize sequencing have been employed to investigate AMR [3]. Additionally, gathering clinical data to create clinical decision support systems may help healthcare providers track trends in antimicrobial resistance to encourage the responsible use of antibiotics [13]. Notably, the majority of previous publications on AMR have also been approached from the perspective of structural and molecular mechanisms [9].

Antibiotics are tiny compounds that can either eliminate or hinder bacteria and are commonly utilized to manage bacterial infections in healthcare settings. Sadly, the misuse of antibiotics leads to AMR. Given that AMR greatly undermines the effectiveness of antibiotics, it is crucial for us to monitor its emergence and dissemination. It is also used in infections that are resistant to antibiotics and the prudent use of these medications, antibiotic combinations and antimicrobial peptides (AMPs)AMPs and combinations of antibiotics provide alternative options for treating infectious diseases and help mitigate the AMR crisis [14].

In recent years, artificial intelligence (AI) has shown significant skill in the area of AMR management. For instance, sequencing-based applications of artificial intelligence have been utilized to investigate AMR. Additionally, gathering clinical data for creating clinical decision support systems may aid healthcare providers in tracking trends in antimicrobial resistance to encourage the prudent use of antibiotics. Moreover, artificial intelligence technologies are frequently utilized in creating new antibiotics and investigating synergistic combinations of medications. Notably, the majority of previous works on AMR have also been approached from the perspective of structural and molecular mechanisms [15].

Limitations and Future Perspectives:

AI has attained an accuracy in healthcare that seemed impossible only a few years back, yet various limitations still hinder its translation into care pathways. Firstly, there is a deficiency, particularly in pediatrics, of randomized clinical trials that show the dependability and/or enhanced efficacy of AI systems relative to conventional systems for diagnosing infectious diseases. A further constraint is the methodological bias that these systems might exhibit since they are frequently founded on studies, databases, and guidelines from different nations that may not reflect all patient populations [16]. The integration of AI, bio-sensing, and digital health will transform AMR detection and monitoring. Prototype experiments will probably evolve into completely integrated, smart bio-sensing systems that function persistently across human, animal, and environmental sectors in the coming ten years. This perspective necessitates collaborative improvements in technology, systems design, regulatory structures, and investigation cooperation.

Conclusion:

The emergence of antimicrobial resistance (AMR) poses a substantial health challenge, leading to approximately 1.27 million deaths annually. AI plays a pivotal role in predicting AMR by analyzing bacterial whole genome sequences, thus improving treatment strategies and surveillance. Traditional methods often overlook emerging AMR determinants. Machine learning (ML) has proven essential in forecasting resistance patterns, with examples of successful models achieving up to 95% accuracy in predicting minimum inhibitory concentrations (MICs). AI facilitates applications in optimizing antibiotic use, predicting infectious diseases, and enhancing drug development. Despite significant advancements, challenges remain in AI adoption, particularly a lack of comprehensive clinical trials, which may limit trust in AI compared to conventional methods. Addressing AMR requires interdisciplinary efforts within the One Health framework. In summary, while AI and big data present transformative potential for managing AMR, ongoing research and refinement are essential to overcome barriers and enhance clinical applications.

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