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Harnessing artificial intelligence for predictive modeling in combating antimicrobial resistance: a call for integration and innovation

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Abstract

Antimicrobial resistance (AMR) represents a critical global health challenge with profound socioeconomic and public health implications. The rise of resistant microorganisms undermines the effectiveness of antibiotics, antivirals, antifungals, and other antimicrobial agents, leading to increased mortality, prolonged illnesses, and escalating medical costs. This study underscores the urgent need for innovative solutions, focusing on the integration of artificial intelligence (AI) to combat AMR. AI, with its rapid data processing, predictive modeling capabilities, and cost-effectiveness, emerges as a transformative tool in mitigating this global crisis. AI-driven predictive models have demonstrated remarkable accuracy in identifying AMR patterns by analyzing vast datasets encompassing patient demographics, antibiotic usage, and environmental factors. These models enhance the precision of antibiotic therapy, guide antimicrobial stewardship programs, and provide early warnings for resistance outbreaks. Furthermore, AI facilitates the development of novel antimicrobial agents, accelerates drug discovery, and supports precision medicine by tailoring treatments to individual patients' profiles. The effective application of AI in addressing AMR necessitates interdisciplinary collaboration among healthcare professionals, microbiologists, policymakers, and AI specialists. This paper calls for robust policy frameworks, dedicated funding, and global partnerships to integrate AI into healthcare systems for AMR surveillance, prevention, and control. Embracing AI innovation is pivotal to safeguarding global public health and ensuring a sustainable future free from the threat of antimicrobial resistance.

Keywords Artificial intelligence, Antimicrobial resistance, Predictive modelling, Global health, Innovation

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Introduction

Antimicrobial resistance (AMR) arises when modifications to microorganisms render drugs used to treat infections ineffective. This has emerged as the main worldwide public health concern in the twenty-first century [1]. AMR is one of the top threats to global health and development, with a challenging socioeconomic impact in developed and developing nations [2]. The burden of AMR is disproportionately high in low- and middle-income countries (LMICs). For example, Sub-Saharan Africa had the highest rate of AMR burden at 23.7 deaths per 100,000 people, while Australasia had the lowest at 6.5 deaths per 100,000 [1]. Infections caused by antimicrobial-resistant organisms are not only difficult to treat; there is always an increased chance of severe illness and eventual death due to their debilitating effect on the host system [3]. Therefore, several types of antimicrobial agents, including antibiotics, antifungals, antivirals, disinfectants, and food preservatives, either suppress the growth and multiplication of microbes or kill them [3]. Nonetheless, the pandemic of resistance to these antimicrobial drugs now requires attention, as AMR continues to pose a serious problem to achieving one health coverage, with resultant outcomes associated with prolonged illnesses, increased medical expenses, and increased mortality rates. To this end, stopping AMR requires swift-coordinated efforts worldwide.

Combating the spread of AMR is a global public health challenge with no simple answer. One of the major barriers to efforts to reduce the excessive use of antimicrobials is their pervasive incorporation into food, animal production, and medical treatment [4]. Modern farming systems rely on the routine administration of antimicrobials to animals for infection control and growth promotion, whereas doctors frequently rely on empirical antibiotic prescriptions due to the lack of rapid point-of-care diagnostics [5]. This AMR epidemic is also largely caused by improper use of antibiotics and insufficient infection control measures. Despite the high level of knowledge on the hazards of resistance associated with antibiotic abuse, antimicrobial stewardship programs in healthcare settings and updated animal husbandry rules are still not widely implemented [5]. In addition, the pipeline for developing newer and more effective drugs is unable to keep up with the ongoing evolution of multidrug resistant bacteria, which further exacerbates these problems [5]. The threat posed by AMR is growing drastically, with the potential to kill millions of people every year and increase mortality rates. Thus, combating its spread cannot be overlooked.

The role of Artificial Intelligence (AI)

Innovative solutions such as the use of artificial intelligence (AI) and machine learning (ML) are urgently required to address these threats. AI is a cutting-edge strategy that accelerates the development of new drugs due to its rapid pace, cost-effectiveness, reduced labor needs, and decreased failure rate [4]. AI has been applied in the discovery of several β-lactamase inhibitors and substitutes for antibiotics from marine natural products, non-ribosomal peptides, antimicrobial peptides (AMPs), and bacteriocins [6]. It is a useful tool for preventing AMR, accelerating and enhancing traditional procedures and strategies, guaranteeing intelligent digitalized patient care and healthcare systems, and reducing human-based errors [6]. Deep learning (DL) is a specialised subset of machine learning that processes data using artificial neural networks with several layers while ML uses simpler algorithms. A recent study developed the MSDeepAMR model, which uses deep learning techniques to analyze raw mass spectrometry (MS) data for predicting AMR in bacterial species such as *Escherichia coli*, *Klebsiella pneumoniae*, and *Staphylococcus aureus* [7].

Considering the sheer amount of biological data generated and embedded in body systems, analyzing and interpreting biological based-data is paramount toward understanding the molecular and cellular processes that foster AMR outcomes. It is possible that the use of AI and ML in developing predictive models can predict AMR patterns. Several studies have demonstrated the effectiveness of machine learning models in predicting AMR microorganisms and their resistance to broad- and narrow-spectrum antibiotics [8]. These models use patient data, microbiology test results, and other relevant features to train algorithms such as XGBoost, LightGBM, and Random Forest to accurately predict antibiotic resistance [9]. High accuracy, sensitivity, and specificity scores have been achieved, indicating the potential of these models to guide empirical antibiotic therapy [9]. AI can analyze large datasets to uncover complex interactions and factors driving AMR, such as patient demographics, comorbidities, antibiotic usage patterns, and environmental conditions [10]. By identifying these critical determinants, AI models can predict how resistance forms and spreads in various settings, particularly in poorly developed areas. Predictive AI models can also be used in early warning systems to identify rising resistance patterns and outbreaks across global radar. By continuously monitoring data sources, these systems can provide timely alerts to healthcare providers, policymakers, and public health authorities, enabling proactive interventions to contain the spread of resistant pathogens [10]. AI-powered models can also be used to forecast an individual patient's probability of harboring resistant infections, thereby promoting a personalized medicine approach. This allows clinicians to adjust antibiotic selection and dosage according to the patient's specific profile, improve treatment outcomes, and minimize selective pressure for resistance [8].

Furthermore, AI can be used to analyze massive datasets from clinical and environmental sources, revealing insights and trends linked to AMR in humans, animals, and plants. AI and ML algorithms can be trained on comprehensive datasets that integrate clinical data (e.g., patient records and microbiological test results) and environmental data (e.g., antibiotic usage patterns, pollution levels, and climate) to develop predictive AMR models [11]. These models allow proactive interventions by predicting the formation and spread of diseases with resistance under various conditions. Moreover, this information can help focus measures, such as improving antibiotic stewardship or reducing environmental pollution, to target the underlying causes of resistance. With the use of AI, a precision approach can enhance the treatment results and reduce the selective pressure for resistance.

Barriers to AI Implementation in AMR Management

The integration of AI in combatting AMR has tremendous opportunities but also faces various hurdles and weaknesses. Understanding these limits is vital for effectively harnessing AI technology in this critical field of public health. Some of the challenges are data availability and model quality, inadequate data might cause biased models that do not generalise well to real-world settings [12]. Lack of transparency can undermine confidence among healthcare professionals and stakeholders, who may be hesitant to depend on AI-driven suggestions without understanding the underlying decision-making process [12]. Furthermore, healthcare providers may show resistance because to worries about reliability and the requirement for training in new technology [12]. The application of AI in healthcare involves ethical considerations, such as patient privacy, data security, and the possibility of algorithmic prejudice. These aspects must be carefully handled to ensure that AI applications do not unintentionally increase existing inequities in healthcare access and outcomes [13].

Call for multisectoral collaboration

Therefore, the increasing threat posed by AMR necessitates an interdisciplinary response that makes use of AI in cooperation with important players in both public and private sectors. The effective integration of AI to anticipate, identify, and control AMR will require close cooperation among public health officials, microbiologists, doctors, and AI specialists. To fully realize AI's promise in the fight against AMR, long-term policy support and committed financing are required. Governments and international organizations must prioritize AMR as a global health security problem and engage in programs to promote AI innovation and integration into healthcare systems. Furthermore, AI can be used to forecast, detect, and control the growing threat of antibiotic resistance by adopting a multidisciplinary approach, obtaining government support and financing, and utilizing the complementary skills of the public and private sectors. This collective effort is critical for protecting the global public health system and ensuring a sustainable future free from AMR.

Conclusions

AMR continues to pose a rising concern to global health, particularly in resource-limited settings. Artificial intelligence provides a holistic solution to this problem by facilitating quick diagnoses, predictive modelling, surveillance, and medication discovery. However, its successful integration into healthcare systems necessitates strong data infrastructures, transparent and ethical AI systems, interdisciplinary collaboration, and ongoing policy backing. Investing in AI-based technologies and building a global coalition are critical to guaranteeing a future in which antimicrobial resistance is efficiently tracked, managed, and minimized.

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Ethical statement
The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Authors' contributions
AMI conceived the idea. AMI, MMA, SSM, MRH, AIA, AMS collected and analysed the data and information and rotated in writing different versions of the drafts with intellectual additions by DELP III. All authors read and approved the final manuscript.

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References

1. Murray CJL, Ikuta KS, Sharara F, Swetschinski L, Aguilar GR, Gray A, et al. Global burden of bacterial antimicrobial resistance in 2019: a systematic analysis. Lancet. 2022;399:629–55.
2. Antimicrobial resistance. Available from: https://www.who.int/news-room/fact-sheets/detail/antimicrobial-resistance. Cited 2024 Jul 8.
3. Salam MA, Al-Amin MY, Salam MT, Pawar JS, Akhter N, Rabaan AA, et al. Antimicrobial resistance: a growing serious threat for global public health. Healthcare. 2023;11:1946.
4. Rahman MM, AlamTumpa MA, Zehravi M, Sarker MT, Yamin M, Islam MR, et al. An overview of antimicrobial stewardship optimization: the use of antibiotics in humans and animals to prevent resistance. Antibiotics. 2022;11:667.
5. Ahmed SK, Hussein S, Qurbani K, Ibrahim RH, Fareeq A, Mahmood KA, et al. Antimicrobial resistance: Impacts, challenges, and future prospects. J Med Surg Public Health. 2024;2:100081.
6. Talat A, Khan AU. Artificial intelligence as a smart approach to develop antimicrobial drug molecules: a paradigm to combat drug-resistant infections. Drug Discov Today. 2023;28:103491.
7. López-Cortés XA, Manríquez-Troncoso JM, Hernández-García R, Peralta D. MSDeepAMR: antimicrobial resistance prediction based on deep neural networks and transfer learning. Front Microbiol. 2024;15. Available from: https://www.frontiersin.org/journals/microbiology/articles/https://doi.org/10.3389/fmicb.2024.1361795/full. Cited 2025 Feb 2.
8. Sakagianni A, Koufopoulou C, Feretzakis G, Kalles D, Verykios VS, Myrianthefs P, et al. Using Machine Learning to Predict Antimicrobial Resistance——A Literature Review. Antibiotics. 2023;12. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC10044642/. Cited 2024 Jul 8.
9. Quoc VT, Ngoc DNT, Hoang TN, Thi HV, Duc MT, Nguyet TDP, et al. Predicting antibiotic resistance in ICUs patients by applying machine learning in Vietnam. Infect Drug Resist. 2023;16:5535–46.
10. Pinto-de-Sá R, Sousa-Pinto B, Costa-de-Oliveira S. Brave new world of artificial intelligence: its use in antimicrobial stewardship—a systematic review. Antibiotics. 2024;13:307.
11. Yang YC, Islam SU, Noor A, Khan S, Afsar W, Nazir S. Influential usage of big data and artificial intelligence in healthcare. Comput Math Methods Med. 2021;2021:5812499.
12. Branda F, Scarpa F. Implications of Artificial Intelligence in Addressing Antimicrobial Resistance: Innovations, Global Challenges, and Healthcare's Future. Antibiotics. 2024;13:502.
13. Artificial intelligence, a powerful tool to combat antimicrobial resistance: An update. JABET. Available from: https://www.bsmiab.org/jabet/178-1693302737-artificial-intelligence-a-powerful-tool-to-combat-antimicrobial-resistance-an-update. Cited 2025 Feb 2.

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