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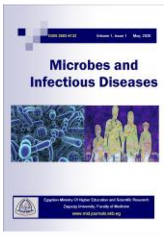

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Mini-review article

Harnessing AI to counteract antimicrobial resistance: A new frontier

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ABSTRACT

Background: The burgeoning crisis of antimicrobial resistance (AMR) poses a grave threat to global health, necessitating innovative solutions that transcend traditional therapeutic approaches. This piece explores the transformative potential of artificial intelligence (AI) as a multifaceted tool in combating AMR. Utilizing advanced algorithms, AI offers promising avenues for predicting antibiotic resistance patterns, expediting drug discovery, optimizing treatment regimens, and enhancing data mining and surveillance. However, the integration of AI into AMR research is fraught with challenges, including ethical quandaries, data integrity issues, algorithmic opacity, resource limitations, and translational obstacles. Through a comprehensive review of existing literature and a detailed analysis of challenges and strategic recommendations, the piece serves as both an overview and a call to action. It advocates for a multi-disciplinary, collaborative approach to harness the untapped potential of AI in the fight against AMR. As we stand on the cusp of a post-antibiotic era, the paper concludes that the responsible and effective integration of AI could be a paradigm shift in global health, offering a compelling impetus for concerted research efforts in this critical area.

Introduction

The escalating antimicrobial resistance (AMR) crisis casts a long, ominous shadow over the landscape of global public health [1, 2]. As we teeter on the edge of a post-antibiotic era, the challenge of AMR looms ever larger, posing an existential threat of daunting proportions [3, 4]. Identified by the World Health Organization as one of the top ten global health threats we currently face, AMR threatens to erode decades of medical progress, returning us to a time when even the most mundane infections could prove fatal [1].

The challenges posed by AMR are manifold, ranging from the scientific complexities of drug development to the economic disincentives for pharmaceutical companies to invest in antibiotic research [5,6]. Moreover, the global nature of AMR necessitates coordinated international efforts, which are often hampered by disparate healthcare systems and regulatory frameworks. In contrast, AI has been making significant strides in healthcare, offering solutions that range from diagnostic algorithms to personalized treatment plans. In the field of drug discovery, AI algorithms have shown promise in expediting the identification of potential new drugs,

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thereby potentially shortening the development pipeline [7]. Machine learning models, in particular, have been effective in analyzing large datasets to identify patterns and make predictions that would be impossible or incredibly time-consuming for humans [8].

The existing literature on the application of AI in combating AMR is an emerging field that has garnered increasing attention in recent years. Several studies have demonstrated the efficacy of machine learning algorithms in predicting antibiotic resistance patterns [9–11], thereby aiding in the selection of appropriate treatment regimens. The reality is that the pipeline for new antibiotics has been drying up, with few pharmaceutical companies investing in antibiotic research due to the low return on investment and the inherent scientific challenges involved [12]. Against this backdrop, the promise of AI in expediting the drug discovery process and potentially leading to the development of new classes of antibiotics presents a glimmer of hope [8]. This development offers a new way to navigate the complex labyrinth of drug discovery, to expedite the arduous journey from bench to bedside that is the hallmark of antibiotic development [5]. The rapid, cost-effective analysis of vast libraries of compounds, identification of potential antibiotics, and prediction of new structural classes are just a few of the promising applications of AI in this context [5,8].

This paper aims to provide a comprehensive overview of the algorithms and models that are particularly promising in this context, delve into the ethical considerations and challenges associated with the implementation of AI in healthcare, and offer recommendations for future research.

The advent of AI in healthcare

AI has begun to make inroads into a plethora of sectors, and healthcare is no exception [5,11]. The confluence of AI with medical research and clinical practice promises to transform the landscape of healthcare, introducing a new paradigm of precision and efficiency [13]. AI's potential in healthcare spans a broad spectrum, ranging from predictive analytics and disease diagnosis to personalized medicine and drug discovery [11,13]. The incorporation of AI in drug discovery has been particularly noteworthy [5.] The traditional process of drug discovery, characterized by high costs, a protracted timeline, and a high attrition rate, is ripe for disruption. AI, with its capabilities in handling vast amounts of data, pattern recognition, and predictive modelling, has shown potential to revolutionize this process [5,6].

Potential of AI in Combating AMR

As we navigate the complex landscape of AMR, AI emerges as a transformative force, offering a diverse array of algorithms with significant potential across multiple facets of AMR research. These algorithms span a wide range of applications, from predicting antibiotic resistance patterns and expediting drug discovery to optimizing treatment regimens and enhancing data mining and surveillance capabilities [8]. Additionally, AI's role in diagnostics is becoming increasingly pivotal, particularly in the identification of antibiotic-resistant infections. Table 1 provides an overview of various AI algorithms that are particularly promising in the context of AMR research, along with their advantages and limitations [33,34].

In the area of predicting antibiotic resistance patterns, algorithms such as SVM have demonstrated considerable efficacy [13–15]. These machine learning models excel in classifying bacterial strains based on their resistance to specific antibiotics, thereby providing invaluable insights for the selection of effective treatment regimens [13–15]. Similarly, Random Forest algorithms have been employed to predict resistance genes in bacterial genomes with remarkable accuracy [17]. The Naive Bayes Classifier, another machine learning model, has also shown promise in predicting antibiotic resistance based on genomic sequence data [18]. These predictive analytics could revolutionize the management of infectious diseases, enabling more targeted and effective treatments that minimize the risk of resistance development.

In diagnostics, Deep Learning algorithms have been employed to analyze medical images to detect infections that may be antibiotic-resistant [20, 21][5,6,8]. NLP algorithms offer another avenue, extracting relevant information from clinical notes to assist in the diagnosis of antibiotic-resistant infections [31]. As we navigate this complex landscape, it becomes increasingly evident that AI offers a range of tools that could significantly impact the way we understand, treat, and manage antibiotic-resistant infections. These algorithms and models represent not just technological innovations but also a beacon of hope for more effective and targeted interventions in this critical battle against AMR.

Unveiling abaucin: A testament to AI's potential

The narrative of abaucin, a ground-breaking antibiotic, paints a vivid picture of the transformative potential of AI in drug discovery, particularly in our escalating battle against AMR. This breakthrough in antibiotic discovery resulted from a strategic fusion of machine learning with microbiology, leveraging the immense computational power of AI to address one of the most pressing challenges in contemporary medicine [6].

The AI model, trained meticulously with a dataset comprising chemical structures with established antibacterial capabilities, was deployed to scrutinize thousands of antibacterial molecules [6]. The aim was to forecast novel structural classes with antibiotic potential - a task that, in the absence of AI, would be dauntingly laborious and financially exorbitant. The fruit of this AI-mediated screening was abaucin, an unprecedented antibacterial compound [6]. Upon the computational revelation of abaucin, the antibiotic was subjected to empirical testing against *Acinetobacter baumannii* [6]. The newly discovered molecule was evaluated in a mouse model of wound infection, where it effectively curtailed the infection [6], thus showcasing its potential as a potent asset in our arsenal of antibiotics.

The story of abaucin underscores the transformative potential of AI in our struggle against AMR. It represents a crucial leap forward in our capacity to employ AI for the discovery of novel antibiotics. As we grapple with the expanding menace of AMR, the advent of abaucin stands as a beacon of optimism, a tangible embodiment of how AI can catalyze the discovery of new antibiotics, potentially reshaping the domain of drug discovery and ushering in a new epoch in our campaign against infectious diseases.

Challenges in the Integration of Artificial Intelligence into Antimicrobial Resistance Research

Ethical and regulatory quandaries

As we delve into the integration of AI in the battle against AMR, we encounter a labyrinth of ethical and regulatory challenges that cannot be overlooked [35]. The deployment of machine learning algorithms in healthcare settings raises intricate questions surrounding data privacy, informed consent, and the potential for algorithmic bias [36]. These ethical complexities are further compounded by the nascent state of regulatory frameworks governing AI in healthcare, which are often fragmented and lack international harmonization.

Data integrity and accessibility

The potency of AI algorithms is inextricably linked to the caliber and volume of the data upon which they are trained [29,30]. The landscape is rife with challenges stemming from inconsistent data collection methodologies, the absence of standardized data formats, and the prevalence of data silos that impede collaborative research.

Algorithmic opacity and interpretability

The enigmatic nature of certain AI algorithms, particularly deep learning models, presents a formidable challenge [20]. These algorithms, often described as "black-box" models[37], offer high predictive accuracy but lack transparency in their decision-making processes. This opacity is particularly problematic in healthcare, where interpretability is not just desirable but often imperative for clinical acceptance [37].

Resource limitations

The computational voracity of advanced AI algorithms poses another significant hurdle, especially in resource-constrained settings [8]. These environments, which ironically are often the hotbeds for AMR, may lack the computational infrastructure required to run complex machine learning models effectively [5].

Translational obstacles

The chasm between AI-assisted discovery and its clinical application is fraught with challenges [21]. The rigorous scientific validation that is a prerequisite for clinical adoption often involves intricate and time-consuming processes, including extensive in vitro studies, animal models, and ultimately, human clinical trials [29,35].

The way forward

The way forward necessitates a multi-disciplinary, collaborative approach that transcends the boundaries of individual specialties and sectors. Ethical and regulatory frameworks must evolve in tandem with technological advancements, ensuring responsible and equitable AI deployment. Investment in high-quality, standardized data repositories is crucial, as is the development of transparent and interpretable algorithms. Moreover, the translational journey from AI-assisted discovery to clinical application requires rigorous scientific validation, facilitated by close collaboration between data scientists, microbiologists, clinicians, and pharmacologists. As we navigate this intricate landscape, a concerted effort is imperative to harness the transformative potential of AI in combating AMR, thereby turning the tide in this critical battle for global health. **Table 2** summarise the challenges and recommendations.

Table 1. Overview of artificial intelligence algorithms AMR research: Applications, advantages, and limitations.

Algorithm	**Application**	**Advantages**	**Limitations**	**Refs**
Support Vector Machines (SVM)	Prediction of Antibiotic Resistance Patterns	High accuracy in classification; Robust against overfitting	Sensitive to parameter settings; May require large datasets	[13–15]
Random Forests	Prediction of Antibiotic Resistance Patterns	Handles large data sets; Provides feature importance	Can overfit on noisy data; Complexity can be high	[16,17]
Naive Bayes Classifier	Prediction of Antibiotic Resistance Patterns	Simple and efficient; Good with high dimensions	Assumes feature independence; Sensitive to irrelevant features	[18]
Convolutional Neural Networks (CNN)	Drug Discovery	Effective in image and pattern recognition; High accuracy	Requires large datasets; Computationally intensive	[19,20]
Generative Adversarial Networks (GANs)	Drug Discovery	Can generate novel molecular structures	Training can be unstable; Requires fine-tuning	[21,22]
Q-Learning	Treatment Optimization	Adapts to changing conditions; Optimizes decision-making	Requires a lot of data; Can be computationally expensive	[23]
Decision Trees	Treatment Optimization	Easy to interpret; Handles missing values	Prone to overfitting; Sensitive to data imbalance	[24]
K-means Clustering	Data Mining and Surveillance	Simple to implement; Efficient in large datasets	Sensitive to initial conditions; Assumes spherical clusters	[25]
Principal Component Analysis (PCA)	Data Mining and Surveillance	Reduces dimensionality; Simplifies data	Loss of original features; Assumes linear correlation	[26,27]
Deep Learning Algorithms	Diagnostics	High accuracy; Can learn complex patterns	Requires large datasets; Black-box nature	[28–30]
Natural Language Processing (NLP)	Diagnostics	Effective in text analysis; Can extract complex relationships	Sensitive to language nuances; Requires clean data	[31,32]

Table 2. Challenges and recommendations in AI for AMR.

Challenge	**Specific Challenges**	**Recommendations**
Ethical and Regulatory Quandaries	Data privacy, informed consent, algorithmic bias	Establish ethical guidelines and regulatory frameworks; foster international collaborations for data governance.
Data Integrity and Accessibility	Inconsistent data collection, lack of standardization, data silos	Invest in high-quality, standardized databases; promote data sharing across public and private sectors.
Algorithmic Opacity and Interpretability	"Black-box" nature of some algorithms, lack of transparency	Focus on developing interpretable machine learning models or hybrid models that are both accurate and interpretable.
Resource Limitations	Computational requirements, lack of infrastructure in low-resource settings	Develop less resource-intensive algorithms; explore cloud-based solutions to mitigate resource constraints.
Translational Obstacles	Rigorous scientific validation, gap between discovery and clinical application	Facilitate multi-disciplinary collaborations for scientific validation and clinical trials.

Conclusion

The escalating crisis of AMR necessitates innovative approaches that transcend traditional boundaries. This paper has demonstrated that AI offers a transformative potential in this critical domain. From its capability to predict antibiotic resistance patterns to its role in expediting drug discovery and optimizing treatment, AI presents a multifaceted solution to a complex problem. However, the integration of AI into AMR research is not without challenges. Ethical considerations, data integrity, algorithmic interpretability, resource constraints, and translational hurdles must be carefully navigated. As we delineate strategic recommendations, it becomes evident that a multi-disciplinary, collaborative approach is essential for the effective implementation of AI in combating AMR. Investment in high-quality data repositories, the development of interpretable algorithms, and international collaborations stand out as key strategies. In the face of a looming post-antibiotic era, the potential of AI to revolutionize our approach to combating AMR cannot be overstated. While challenges abound, the promise of AI offers a compelling impetus for concerted efforts in this critical area of global health. Future research should focus on addressing the identified challenges, thereby paving the way for the responsible and effective integration of AI into AMR research.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Availability of data and material

Not applicable.

Competing interests

The authors declare no conflict of interest.

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Authors' contributions

B.H.G conceived the idea. All authors wrote, reviewed and approved the manuscript.

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References

1-**World Health Organization** (**WHO**). Antimicrobial resistance 2021. https://www.who.int/news-room/fact-sheets/detail/antimicrobial-resistance (accessed May 24, 2023).

2- **O'Neill J.** Tackling drug-resistant infections globally: final report and recommendations. Government of the United Kingdom 2016.

3- **Gulumbe BH, Haruna UA, Almazan J, Ibrahim IH, Faggo AA, Bazata AY.** Combating the menace of antimicrobial resistance in Africa: a review on stewardship, surveillance and diagnostic strategies. Biol Proced Online 2022;24:19.

4- **Gulumbe BH, Sahal MR, Abdulrahim A, Faggo AA, Yusuf ZM, Sambo KH, et al.** Antibiotic resistance and the COVID-19 pandemic: A dual crisis with complex challenges in LMICs. Health Sci Rep 2023;6:e1566.

5- **Stokes JM, Yang K, Swanson K, Jin W, Cubillos-Ruiz A, Donghia NM, et al.** A Deep Learning Approach to Antibiotic Discovery. Cell 2020;181:475–83.

6- **Liu G, Catacutan DB, Rathod K, Swanson K, Jin W, Mohammed JC, et al.** Deep learning-guided discovery of an antibiotic targeting Acinetobacter baumannii. Nat Chem Biol 2023:1–9.

7- **Paul D, Sanap G, Shenoy S, Kalyane D, Kalia K, Tekade RK.** Artificial intelligence in drug discovery and development. Drug Discov Today 2021;26:80–93.

8- **Tran M-H, Nguyen NQ, Pham HT.** A New Hope in the Fight Against Antimicrobial Resistance with Artificial Intelligence. Infect Drug Resist 2022; 15:2685–8.

9- **Kim JI, Maguire F, Tsang KK, Gouliouris T, Peacock SJ, McAllister TA, et al.** Machine Learning for Antimicrobial Resistance Prediction: Current Practice, Limitations, and Clinical Perspective. Clin Microbiol Rev 2022;35:e00179-21.

10- **Tang R, Luo R, Tang S, Song H, Chen X.** Machine learning in predicting antimicrobial resistance: a systematic review and meta-analysis. Int J Antimicrob Agents 2022;60:106684.

11- **Lv J, Deng S, Zhang L.** A review of artificial intelligence applications for antimicrobial resistance. Biosaf Health 2021;3:22–31.

12- Antibiotics in the clinical pipeline as of December 2022 | The Journal of Antibiotics n.d. https://www.nature.com/articles/s41429-023-00629-8 (accessed November 22, 2023).

13- **Liu Z, Deng D, Lu H, Sun J, Lv L, Li S, et al.** Evaluation of Machine Learning Models for Predicting Antimicrobial Resistance of Actinobacillus pleuropneumoniae From Whole Genome Sequences. Front Microbiol 2020;11:48.

14- **Pesesky MW, Hussain T, Wallace M, Patel S, Andleeb S, Burnham C-AD, et al.** Evaluation of Machine Learning and Rules-Based Approaches for Predicting Antimicrobial Resistance Profiles in Gram-negative Bacilli from Whole Genome Sequence Data. Front Microbiol 2016;7:1887.

15- **Sakagianni A, Koufopoulou C, Feretzakis G, Kalles D, Verykios VS, Myrianthefs P, et al.** Using Machine Learning to Predict Antimicrobial Resistance-A Literature Review. Antibiot Basel Switz 2023;12:452.

16- **Prediction of Acquired Antimicrobial Resistance for Multiple Bacterial Species Using Neural Networks | mSystems n.d.** https://journals.asm.org/doi/full/10.1128/msystems.00774-19 (accessed November 23, 2023).

17- **Xie X, Li X, Sheng Y, Gu B.** Prediction of Antimicrobial Resistance Based on Random Forest Algorithms 2019.

18- **Kang D, Pang X, Lian W, Xu L, Wang J, Jia H, et al.** Discovery of VEGFR2 inhibitors by integrating naïve Bayesian classification, molecular docking and drug screening approaches. RSC Adv 2018;8:5286–97.

19- **Grebner C, Matter H, Kofink D, Wenzel J, Schmidt F, Hessler G.** Application of Deep Neural Network Models in Drug Discovery Programs. ChemMedChem 2021;16:3772–86.

20- **Gawehn E, Hiss JA, Schneider G.** Deep Learning in Drug Discovery. Mol Inform 2016;35:3–14.

21- **Tripathi S, Augustin AI, Dunlop A, Sukumaran R, Dheer S, Zavalny A, et al.** Recent advances and application of generative adversarial networks in drug discovery, development, and targeting. Artif Intell Life Sci 2022;2:100045.

22- **Hussain S, Anees A, Das A, Nguyen BP, Marzuki M, Lin S, et al.** High-content image generation for drug discovery using generative adversarial networks. Neural Netw 2020;132:353–63.

23- **Moodie EEM, Chakraborty B, Kramer MS.** Q-learning for estimating optimal dynamic treatment rules from observational data. Can J Stat 2012;40:629–45.

24- **Chrimes D.** Using Decision Trees as an Expert System for Clinical Decision Support for COVID-19. Interact J Med Res 2023;12:e42540.

25- **Lei J, Jiang T, Wu K, Du H, Zhu G, Wang Z.** Robust K-means algorithm with automatically splitting and merging clusters and its applications for surveillance data. Multimed Tools Appl 2016;75:12043–59.

26- **Port JA, Cullen AC, Wallace JC, Smith MN, Faustman EM**. Metagenomic Frameworks for Monitoring Antibiotic Resistance in Aquatic Environments. Environ Health Perspect 2014;122:222–8.

27- **Bouwmans T, Zahzah EH.** Robust PCA via Principal Component Pursuit: A review for a comparative evaluation in video surveillance. Comput Vis Image Underst 2014;122:22–34.

28- **Myszczynska MA, Ojamies PN, Lacoste AMB, Neil D, Saffari A, Mead R, et al.** Applications of machine learning to diagnosis and treatment of neurodegenerative diseases. Nat Rev Neurol 2020;16:440–56.

29- **Ahsan MM, Luna SA, Siddique Z.** Machine-Learning-Based Disease Diagnosis: A Comprehensive Review. Healthcare 2022;10:541.

30- **Wu S, Wang J, Guo Q, Lan H, Zhang J, Wang L, et al.** Application of artificial intelligence in clinical diagnosis and treatment: an overview of systematic reviews. Intell Med 2022;2:88–96.

31- **Buchlak QD, Esmaili N, Bennett C, Farrokhi F.** Natural Language Processing Applications in the Clinical Neurosciences: A Machine Learning Augmented Systematic Review. Acta Neurochir Suppl 2022;134:277–89.

32- **Locke S, Bashall A, Al-Adely S, Moore J, Wilson A, Kitchen GB.** Natural language processing in medicine: A review. Trends Anaesth Crit Care 2021;38:4–9.

33- **Shah K, Patel H, Sanghvi D, Shah M.** A Comparative Analysis of Logistic Regression, Random Forest and KNN Models for the Text Classification. Augment Hum Res 2020;5:12.

34- **Rivest M, Vignola-Gagné E, Archambault É.** Article-level classification of scientific publications: A comparison of deep learning, direct citation and bibliographic coupling. PLOS ONE 2021;16:e0251493.

35- **Rajpurkar P, Chen E, Banerjee O, Topol EJ.** AI in health and medicine. Nat Med 2022;28:31–8. https://doi.org/10.1038/s41591-021-01614-0.

36- **Blanchard AE, Stanley C, Bhowmik D.** Using GANs with adaptive training data to search for new molecules. J Cheminformatics 2021;13:14.

37- **Rai A.** Explainable AI: from black box to glass box. J Acad Mark Sci 2020;48:137–41.

Gulumbe BH, Yusuf AB, Abdulrahim A, Liman UU. Harnessing AI to counteract antimicrobial resistance: A new frontier. Microbes Infect Dis 202 Article-In-Press, **DOI:** 10.21608/mid.2023.250773.1675.