News and Perspective

Tracking Superbugs in the Digital Era

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Key Takeaways

- Data-driven diagnostics leveraging artificial intelligence, machine learning, and whole-genome sequencing are improving how hospitals identify and prevent antimicrobial resistance.
- Digital collaboration enables faster outbreak response and wiser antibiotic use.
- Equitable access and infrastructure are critical for all countries to benefit from such innovations.

A patient in Beirut presents with what appears to be a simple infection. After multiple ineffective courses of antibiotics, laboratory results reveal a strain of *Klebsiella pneumoniae*—resistant to nearly all available medications. Stories like this are becoming all too common in Lebanon and around the world.

Antimicrobial resistance (AMR) happens when bacteria evolve to outsmart some of the strongest antibiotics, and it has become one of the biggest threats to modern medicine. The Centers for Disease Control and Prevention (CDC) estimates that each year, antibiotic-resistant infections claim at least 1.3 million lives in the United States alone [1]. Recent global projections estimate over 2 million attributable deaths and more than 8 million associated deaths annually by 2050 [2].

Yet, while COVID-19 and other outbreaks have gained attention, overuse and misuse of antimicrobials have allowed superbugs to silently continue their spread. Without effective antibiotics, even routine surgeries or childbirth may well become risky again [3].

To take on this invisible pandemic, hospitals and research laboratories—like Siblin Governmental Hospital, where I work in the Molecular Biology department—are building on traditional approaches to AMR detection by leveraging genomic sequencing, artificial intelligence (AI), and machine learning (ML) to facilitate detection of resistant bacteria the moment they appear, sometimes even before an outbreak begins [4,5].

Evolving Tools for AMR Detection

Traditionally, detecting antibiotic resistance relied on culture-based methods, which could take days or even weeks to return a result. During that time, patients were often treated empirically with broad-spectrum antibiotics, which can worsen resistance and delay effective treatment.

Molecular modalities like polymerase chain reaction (PCR) and whole-genome sequencing (WGS) have transformed diagnostics. These techniques can identify resistance genes in a few hours and thus enable the physician to tailor therapy rapidly. For instance, WGS can identify genes that produce carbapenemase enzymes, which are proteins that break down carbapenem antibiotics, powerful drugs often considered the last line of defense, which in turn render those drugs ineffective. Example genes include *blaKPC* or *NDM-1*.

Metagenomic sequencing goes one step further by screening for multiple pathogens and their resistance genes from a single sample. In one European hospital, rapid genome sequencing contained an outbreak of carbapenem-resistant *Klebsiella* within days, thus preventing further spread [6].

AMR Prediction Tools

AI and ML are further improving our response to AMR. Predictive models, trained on large genomic datasets, can forecast which bacterial strains are likely to develop resistance next—imagine a "weather forecast" for superbugs, a sort of dashboard that would alert clinicians when selected pathogens such as methicillin-resistant *Staphylococcus aureus* or drug-resistant *Pseudomonas aeruginosa* are on the rise. Such information would allow hospitals to adjust their use of antibiotics and infection-control measures proactively.

Indeed, many hospitals do now utilize AI-driven dashboards that alert infection-control teams in real time when resistant bacteria are detected. In one such pilot study, these dashboards reduced unnecessary broad-spectrum antibiotic use by 17%-28%, saving both time and money while improving outcomes [7].

These predictive tools not only improve patient care but also help preserve the effectiveness of existing antibiotics. Every unnecessary dose we avoid safeguards these lifesaving drugs for future patients.

Global Surveillance Gets Smarter

Scaling these innovations to support global surveillance requires robust, interoperable digital infrastructure. The field of public health informatics (PHI) provides frameworks and standards for integrating clinical data, laboratory systems, electronic health records, and national surveillance platforms to facilitate near real-time decision-making. Without strong PHI systems, even the most advanced tools, such as WGS or predictive analytics, cannot be appropriately deployed at scale.

This type of infrastructure is beginning to take shape. For example, the World Health Organization's web-based Global Antimicrobial Resistance and Use Surveillance System (GLASS) and the National Center for Biotechnology Information (NCBI) Pathogen Detection Portal provide cloud-based systems where laboratories all over the world can share genomic and clinical data in near real time [4, 8]. ML algorithms can analyze this huge flow of data by flagging unusual resistance patterns and thus alerting health authorities. For example, GLASS data tracked a multicountry outbreak of resistant *Acinetobacter* in Europe and enabled early interventions before further spread [6].

Surveillance and Detection Initiatives in Lebanon

In Lebanon, against the background of a fragile health system, meaningful contributions to AMR surveillance and digital innovation have originated from several laboratories and medical centers.

Rapid PCR assays and semiautomated susceptibility testing systems that reduce diagnostic delays for extended-spectrum β-lactamases (ESBL) and carbapenemase-producing *Enterobacteriaceae* have been increasingly adopted by governmental hospitals, including Siblin. Whole-genome sequencing data is now being generated by academic and clinical centers in the country, and generated sequences are being deposited into regional and international databases, enabling Lebanese strains of *Klebsiella pneumoniae*, *Acinetobacter baumannii*, and *Pseudomonas aeruginosa* to be tracked worldwide. Locally developed dashboards, even on basic Excel spreadsheets or open-source platforms, flag resistance clusters and guide antimicrobial stewardship discussions. These incremental advances demonstrate that Lebanon, despite its infrastructure limitations, is actively participating in global efforts toward better characterization, detection, and anticipation of AMR.

Particularly in governmental and peripheral hospitals, AI-driven molecular diagnostics have already shifted daily practice. For example, the integration of rapid PCR, digital result reporting, and automated interpretation algorithms in Siblin Governmental Hospital has reduced empirical antibiotic use and improved detection of carbapenemase-producing *Enterobacteriaceae*.

Several other universities and laboratories are now piloting ML-based tools that automatically flag unusual antimicrobial susceptibility testing (AST profiles), predict the likelihood of ESBLs or New Delhi metallo-β-lactamase based on local trends, and support infection-control decisions. These small but growing initiatives underline how data-driven tools can strengthen AMR strategies even in resource-limited settings.

Challenges on the Front Lines

These new tools are improving AMR detection and response in Lebanon and globally; however, there are many challenges.

Most low- and middle-income countries lack the resources and infrastructure needed to perform genomic sequencing or share data in real time [8,9]. Technology alone cannot overcome AMR; it must be underpinned by investment in laboratories, internet connectivity, and workforce training.

AMR also presents a set of special difficulties for AI/ML applications, including a limited number of high-quality local datasets, fast-evolving resistance mechanisms, pathogen diversity, and real-time integration of laboratory and clinical data [5]. These applications also raise ethical concerns: data privacy, algorithmic bias, and unequal access to new technologies are likely to widen the gap in global health. Ensuring that AI and digital tools benefit all populations, not just well-resourced hospitals, is vital.

Looking to the Future

The future of effective AMR management is in addressing these challenges and developing integrated digital ecosystems that connect detection, surveillance, and response. AI dashboards, open-access genomic databases, and predictive analytics are receiving growing support from governments and research institutions. The G7 Global AMR Innovation Fund, for example, connects sequencing hubs across continents to produce near real-time global maps of resistance [8].

AMR remains a pervasive and urgent global challenge, but by combining human expertise with digital intelligence and robust PHI infrastructure, we are better equipped to detect, track, and curb the spread of resistance.

Keywords: antimicrobial resistance; digital epidemiology; molecular diagnostics; machine learning; genomic surveillance; precision medicine; infection control

Conflicts of Interest

None declared.

References

1. Antibiotic resistance threats in the United States 2021–2022. Centers for Disease Control and Prevention. 2022. URL: https://www.cdc.gov/antimicrobial-resistance/data-research/threats/update-2022.html [Accessed 2025-12-03]
2. Naghavi M, Vollset SE, Ikuta KS, et al. Global burden of bacterial antimicrobial resistance 1990–2021: a systematic analysis with forecasts to 2050. The Lancet. Sep 2024;404(10459):1199-1226. [doi: 10.1016/S0140-6736(24)01867-1]

3. Tang KWK, Millar BC, Moore JE. Antimicrobial resistance (AMR). Br J Biomed Sci. 2023;80:11387. [doi: 10.3389/bjbs.2023.11387] [Medline: 37448857]
4. Global antimicrobial resistance and use surveillance system (GLASS) report 2022. World Health Organization. 2022. URL: https://www.who.int/pubLications/i/item/9789240062702 [Accessed 2025-12-03]
5. Kim JI, Maguire F, Tsang KK, et al. Machine learning for antimicrobial resistance prediction: current practice, limitations, and clinical perspective. Clin Microbiol Rev. Sep 21, 2022;35(3):e0017921. [doi: 10.1128/cmr.00179-21] [Medline: 35612324]
6. Annual epidemiological report on antimicrobial resistance 2024. European Centre for Disease Prevention and Control (ECDC). URL: https://www.ecdc.europa.eu/en/publications-data/monitoring/all-annual-epidemiological-reports [Accessed 2025-12-03]
7. Vargas B. Automated patient risk assessment lowers antibiotic prescribing rates. Medscape. Apr 24, 2024. URL: https://www.medscape.com/viewarticle/automated-patient-risk-assessment-lowers-antibiotic-2024a1000801 [Accessed 2025-12-03]
8. Rawson TM, Zhu N, Galiwango R, et al. Using digital health technologies to optimise antimicrobial use globally. Lancet Digit Health. Dec 2024;6(12):e914-e925. [doi: 10.1016/S2589-7500(24)00198-5] [Medline: 39547912]
9. Challenges to tackling antimicrobial resistance: economic and policy response. Organisation for Economic Co-operation and Development (OECD). URL: https://www.oecd.org/en/publications/challenges-to-tackling-antimicrobial-resistance_9781108864121.html [Accessed 2025-12-03]

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