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A Narrative Review of Pharmacy-Led Antimicrobial Stewardship Integrated with Radiology and Lab Diagnostics for Epidemiological Tracking of Hospital-Acquired Infections under Health Administration Oversight

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Abstract

Background: Hospital-acquired infections (HAIs) and antimicrobial resistance (AMR) represent critical threats to global health security, straining healthcare systems and worsening patient outcomes. Traditional antimicrobial stewardship (AMS) programs, while essential, often operate in clinical silos, lacking integration with key diagnostic and epidemiological data streams. This fragmentation impedes timely, targeted interventions and holistic infection control. **Aim:** This narrative review aims to synthesize current evidence on the impact, implementation strategies, and outcomes of integrating pharmacy-led AMS with radiology and laboratory diagnostic data under coordinated health administration oversight, specifically for the epidemiological tracking and management of HAIs. **Methods:** A comprehensive literature search was conducted across PubMed, Scopus, and Web of Science for studies published between 2010 and 2024, focusing on interdisciplinary AMS models, diagnostic stewardship, and HAI surveillance. **Results:** The synthesized evidence demonstrates that integrated models significantly enhance early HAI detection, optimize antimicrobial use, and improve patient outcomes by leveraging real-time data analytics and interdisciplinary collaboration. **Conclusion:** A synergistic, administratively supported model that unites pharmacy expertise, advanced diagnostics, and epidemiological tracking is paramount for a proactive, data-driven defense against HAIs and AMR.

Keywords: Antimicrobial Stewardship; Hospital-Acquired Infections; Diagnostic Stewardship; Interdisciplinary Collaboration; Health Administration.

Introduction

The dual burden of hospital-acquired infections (HAIs) and antimicrobial resistance (AMR) constitutes one of the most pressing challenges in modern healthcare, leading to significant morbidity, mortality, and economic cost (World Health Organization, 2022). HAIs, defined as infections not present or incubating at the time of hospital admission, affect millions of patients globally annually, with resistant organisms increasingly implicated (Cassini et al., 2019). Antimicrobial stewardship (AMS) programs, coordinated interventions designed to measure and improve the appropriate use of antimicrobials, have emerged as a cornerstone of the response (Barlam et al., 2016). Traditionally, pharmacy-led AMS teams have focused on post-prescription review and restriction, relying heavily on microbiology laboratory data. However, this approach often reacts to established infections and resistance patterns rather than preventing their emergence and spread.

The siloed operation of AMS, clinical microbiology, radiology, and infection prevention and control (IPC) departments is a recognized barrier to effective HAI management (Poss-Doering et al., 2021). This review posits that a transformative approach is required: the deep integration of pharmacy-led AMS with radiological and laboratory diagnostic pathways, underpinned by robust epidemiological tracking and empowered by proactive health administration oversight. Such a model moves from reactive review to proactive, pre-emptive management of infection risk, leveraging data as a unified strategic asset.

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The Evolving Role of the Pharmacist in Antimicrobial Stewardship

The clinical pharmacist has transitioned from a drug dispenser to an integral member of the antimicrobial stewardship team, a shift validated by numerous studies and guidelines (Barlam et al., 2016; Doron & Davidson, 2011). Pharmacists contribute unique expertise in pharmacokinetics/pharmacodynamics, antimicrobial pharmacology, and medication safety, making them pivotal in designing and implementing stewardship interventions (MacBrayne et al., 2021). Core activities include prospective audit and feedback, formulary restriction and pre-authorization, guideline development, and patient education (Barlam et al., 2016). However, the effectiveness of these traditional pharmacy-centric activities is inherently limited by the timeliness and scope of the information available. A pharmacist reviewing a culture days after collection is addressing a historical event. The contemporary vision for the AMS pharmacist is as a nexus point for clinical, microbiological, and imaging data, interpreting this confluence to guide real-time therapy (Blanchette et al., 2018; Rivera et al., 2021). This expanded role necessitates not only advanced infectious diseases training but also competence in data interpretation and interdisciplinary communication, positioning the pharmacist to orchestrate care based on a comprehensive diagnostic picture rather than isolated laboratory results.

Laboratory Diagnostics: The Foundation for Stewardship and Surveillance

The clinical microbiology laboratory is the engine of evidence-based AMS and HAI surveillance. The integration of rapid diagnostic technologies (RDTs) has been a game-changer, reducing time to organism identification and resistance detection from days to hours (Bauer et al., 2020). Technologies like multiplex polymerase chain reaction (PCR) panels, MALDI-TOF mass spectrometry, and next-generation sequencing provide critical data that, when acted upon swiftly by AMS teams, can significantly improve outcomes (Banerjee et al., 2015). However, diagnostic stewardship—the coordinated guidance on test ordering, collection, interpretation, and application—is as crucial as the technology itself (Morgan et al., 2017).

Pharmacy-led AMS must collaborate closely with laboratory professionals to define appropriate test indications, reject inappropriate samples, and create cascading reporting protocols that guide therapy (Messacar et al., 2017). Beyond individual patient care, aggregated, geocoded laboratory data is the lifeblood of epidemiological tracking. Patterns in resistance (e.g., rising carbapenem-resistant *Enterobacteriaceae* (CRE) rates) or specific organism clusters (e.g., *C. auris*) can be detected early through laboratory surveillance (Avdic & Carroll, 2014). Integrating this surveillance data directly into AMS pharmacist workflows allows for proactive, unit-specific interventions, such as targeted education or pre-emptive guideline adjustments, before outbreaks become entrenched (Timbrook et al., 2017).

Radiology as a Critical, Underutilized Component in the AMS Pathway

Radiological imaging is frequently the first objective indicator of a deep-seated or evolving infection, often preceding microbiological confirmation. Radiology reports describing new pulmonary infiltrates, abscess formations, or collections provide critical, time-sensitive clues (Xu et al., 2022). However, this information often resides in isolated reports, not systematically integrated into AMS algorithms. Integration involves both technological and procedural innovation. Natural language processing (NLP) can be employed to scan radiology reports for key terms (e.g., "new consolidation," "possible abscess") and flag these cases automatically for AMS review (Lakhani et al., 2018). Furthermore, interventional radiology (IR) plays a direct therapeutic role. The ability to percutaneously drain an abscess can be definitive therapy or a crucial adjunct, allowing for source control and enabling narrower-spectrum antimicrobial therapy (Silverman et al., 2016).

An integrated model ensures close collaboration between IR, infectious diseases, and pharmacy: the interventional radiologist performs the drain, the microbiologist cultures the aspirate, and the pharmacist optimizes the antimicrobial regimen based on the combined imaging and microbiological data. This synergy prevents unnecessary prolonged empiric broad-spectrum therapy when source control is achieved.

Epidemiological Tracking: Synthesizing Data for Population Health Management

The true power of integration is realized in the epidemiological tracking of HAIs (Figure 1). Isolated data points—a positive blood culture, a chest X-ray report—become powerful signals when aggregated, analyzed, and mapped. Modern electronic health records (EHRs) and data warehouses allow for the synthesis of pharmacy (antimicrobial usage), laboratory (culture and sensitivity, RDT results), and radiology (imaging frequency and findings) data (Rezel-Potts & Gulliford, 2023). Advanced analytics, including dashboard visualization and statistical process control charts, can identify aberrations in real-time: a spike in antipseudomonal prescribing in the ICU coinciding with a cluster of *Pseudomonas* isolates from respiratory samples (Kuper & Hamilton, 2020). Pharmacy-led AMS teams, equipped with these dashboards, can transition from reviewing individual charts to monitoring population-level antimicrobial pressure and resistance trends. This enables targeted, hypothesis-driven audits. For instance, an increase in chest imaging and vancomycin use on a ward could trigger a focused review of pneumonia diagnosis and treatment adherence to guidelines, potentially identifying and correcting a local practice drift (Watkins & Deresinski, 2019). This data-driven approach transforms AMS from a universal, somewhat scattergun effort into a precise, intelligence-led operation focused on areas of highest risk.

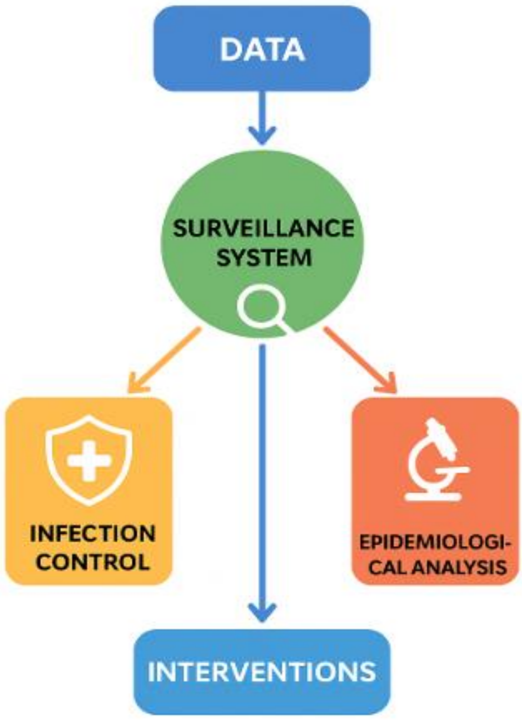

Figure 1: HAI epidemiological tracking framework.

The Imperative of Health Administration Oversight and Resource Allocation

The successful integration of these complex, cross-disciplinary functions cannot occur organically; it requires deliberate and sustained health administration oversight and support. Hospital leadership must create the governance structures that mandate collaboration, break down inter-departmental barriers, and align incentives (Maraolo et al., 2019). This includes establishing a high-level steering committee with representation from pharmacy, microbiology, radiology, infection control, IT, and administration to set strategy and monitor outcomes (Polidori et al., 2022).

Crucially, the administration must commit the necessary resources. This involves funding for advanced diagnostic technologies, IT infrastructure for data integration and analytics platforms, and, most importantly, dedicated personnel time (Charani et al., 2013). Pharmacists, microbiologists, and data analysts need protected time to engage in stewardship activities beyond their routine clinical duties. Administration also plays a key role in linking AMS outcomes to quality improvement and value-based purchasing metrics, making the business case for investment (Moehring et al., 2017). By fostering a culture of safety and interdisciplinary accountability, leadership ensures that the integrated model is embedded into the hospital's operational fabric.

Implementation Strategies and Operational Frameworks

Translating the conceptual model of integrated antimicrobial stewardship (AMS) into daily practice necessitates a structured and phased operational framework. A stepwise implementation is widely advocated, beginning with the consolidation of the foundational partnership between pharmacy and microbiology departments before progressively incorporating radiology data streams and advanced epidemiological analytics (Barlam et al., 2016). This incremental approach allows for the refinement of core processes, builds trust among key stakeholders, and demonstrates early value, thereby securing the support necessary for subsequent, more complex integration phases. Successful implementation hinges on embedding several key operational components into the clinical workflow to ensure sustainability and impact.

A critical technological component is the development of integrated Electronic Health Record (EHR) tools and clinical decision support (CDS) systems. These systems should be designed to synthesize disparate data streams, triggering intelligent alerts for the AMS team. For instance, an alert could be activated when a broad-spectrum antimicrobial is prescribed for a patient with a new radiological finding suggestive of infection, but without corresponding microbiological cultures having been obtained. This immediate signal enables the AMS pharmacist to contact the prescriber promptly to discuss diagnostic stewardship and the importance of culturing before initiating therapy, thereby optimizing both diagnostic yield and empirical treatment choices (Thursky & Mahemoff, 2007). Beyond reactive alerts, proactive interdisciplinary collaboration must be formalized through structured forums such as regular "diagnostic management team" rounds. These sessions, convening the AMS pharmacist, clinical microbiologist, radiologist, and infectious diseases physician, provide a platform for reviewing complex cases by collectively interpreting laboratory results, imaging studies, and clinical progress. This collaborative review leverages all available diagnostic data to reach a consensus on diagnosis, duration of therapy, and the need for further intervention or source control, thereby optimizing patient management (Chia et al., 2020).

To support population health management and drive accountability, the creation of unified surveillance dashboards is essential. These customized data visualization tools aggregate and display real-time metrics from across the integrated system, such as unit-specific antimicrobial consumption, emerging resistance patterns, culture positivity rates correlated with imaging orders, and compliance with institutional treatment pathways. Disseminating these dashboards to clinical unit leaders, the AMS team, and hospital administration fosters transparency, highlights areas for improvement, and enables data-driven interventions. By making epidemiological trends visible, these dashboards empower frontline staff and leaders to take ownership of local antimicrobial use and infection outcomes (Alawi & Darwesh, 2016; Shafiq et al., 2016).

Finally, the development and enforcement of evidence-based, institution-specific clinical protocols and pathways are fundamental to standardizing care. These algorithms must explicitly incorporate diagnostic stewardship principles, specifying when and how to use imaging and laboratory testing within condition-specific pathways for common infections like community-acquired pneumonia or intra-abdominal infections. By providing clear, stepwise guidance that integrates diagnostic and therapeutic decisions, these protocols reduce unwarranted variation, improve the quality of diagnostic data available for stewardship, and ensure patient care aligns with best practices (Metlay et al., 2019). This incremental approach allows for the refinement of core processes, builds trust among key stakeholders, and demonstrates early value. The success of this model relies on the synergistic interaction of distinct but interconnected components, each contributing unique data and expertise to a unified system, as outlined in Table 1 and Figure 2.

Table 1: Core Components and Synergies of an Integrated AMS Model

Component	Key Functions	Data Input for AMS	Synergistic Link to Other Components
Pharmacy-Led AMS	Prospective audit & feedback; Guideline development; Education; Pharmacokinetic monitoring.	Antimicrobial consumption data; Intervention outcomes.	Acts on lab/radiology alerts; uses epidemiological data to target interventions; educates based on local trends.
Laboratory Diagnostics	Rapid pathogen ID & resistance detection; Diagnostic stewardship; Aggregated susceptibility reporting.	Culture results; RDT results; Antibiograms; MDRO alerts.	Informs pharmacist reviews; provides data for epidemiological dashboards; guides radiological follow-up.
Radiology	Early infection detection; Assessment of treatment response; Guidance for source control (IR).	Imaging reports (text/NLP); Procedure notes (drainage).	Triggers AMS review for new findings; provides clinical context for lab results.
Epidemiological Tracking	HAI surveillance; Antimicrobial use monitoring; Data aggregation & visualization.	Integrated datasets (drugs, bugs, images); Statistical alerts for clusters.	Informs AMS priorities; provides evidence for administration; measures impact of interventions.
Health Administration	Governance; Resource allocation; Quality metric integration; Culture cultivation.	Program outcomes; Cost & utilization data.	Mandates collaboration; funds technology & personnel; aligns goals across departments.

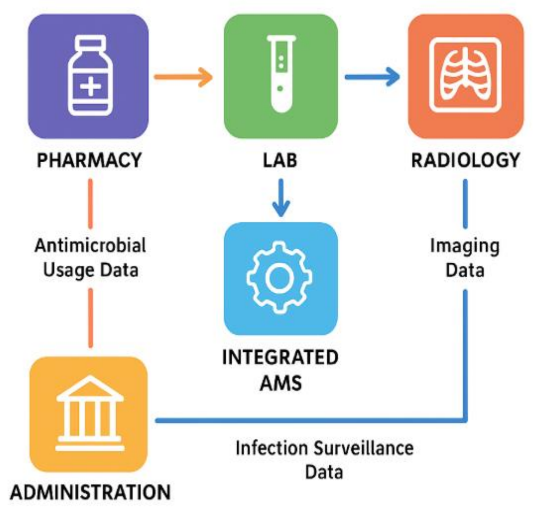

Figure 2: Data flow between lab, pharmacy, radiology, and administration.

Outcomes and Impact of Integrated Models

A growing body of evidence supports the superior outcomes of integrated, data-driven AMS models. Studies demonstrate that integrating RDTs with pharmacist intervention significantly reduces time to effective therapy, decreases mortality, and shortens hospital length of stay (Bauer et al., 2020; Timbrook et al., 2017). Furthermore, programs that incorporate epidemiological surveillance and proactive interventions show sustained reductions in targeted multidrug-resistant organism (MDRO) rates and overall antimicrobial consumption (Perez et al., 2014).

The integration of radiology data, while less studied, contributes to more accurate diagnosis of treatment failure or complications, preventing unnecessary antibiotic escalation and prompting timely source control (Xu et al., 2022). From an administrative perspective, these models demonstrate a strong return on investment through avoided costs of prolonged hospitalization, expensive salvage therapies, and outbreak management (Nelson et al., 2021). Perhaps most importantly, they foster a culture of collective responsibility for antimicrobial preservation and infection prevention, engaging clinicians across disciplines in a shared mission. The comparative advantages are summarized in Table 2, demonstrating a shift from reactive, generalized interventions to proactive, precision stewardship.

Table 2: Measurable Outcomes of Integrated vs. Traditional Siloed AMS Approaches

Outcome Metric	Traditional Siloed AMS	Integrated AMS Model	Supporting Evidence
Time to Optimal Therapy	Slower, often post-culture review (48-72 hrs).	Faster, triggered by RDTs and imaging (often <24 hrs).	Bauer et al., 2020; Timbrook et al., 2017
Antimicrobial Consumption	Reductions are possible, but may be broad.	More targeted reductions; able to de-escalate faster.	Perez et al., 2014; Barlam et al., 2016
HAI/MDRO Rates	Reactive containment of outbreaks.	Proactive suppression through early detection & targeted interventions.	Poss-Doering et al., 2021; Avdic & Carroll, 2014
Clinical Outcomes	Mixed, often modest improvements.	More consistent improvements are shown.	Timbrook et al., 2017; Nelson et al., 2021
Cost-Effectiveness	Cost-saving, but the return may be limited.	Enhanced ROI via avoided complications & outbreaks.	Moehring et al., 2017; Nelson et al., 2021
Clinician Engagement	Often perceived as restrictive/police-like.	Fosters a collaborative, consultative culture as a diagnostic partner.	Polidori et al., 2022; Rivera et al., 2021

Challenges and Future Directions

Despite the compelling rationale, significant challenges persist. These include the high initial cost of technology, interoperability issues between disparate IT systems, professional territoriality, and the need for continuous training of the workforce in data literacy (Grech et al., 2021). Future directions will likely involve greater use of artificial intelligence (AI) and machine learning to predict infection risk, interpret complex imaging, and recommend personalized antimicrobial regimens (Sakagianni et al., 2023). The expansion of rapid molecular diagnostics to directly detect resistance genes and the integration of pharmacokinetic monitoring into dashboards will further personalize therapy (Tiwari et al., 2022). Ultimately, the goal is a learning health system where every diagnostic datum—from a PCR result to a CT scan finding—feeds into a continuously refined model of care, enabling pre-emptive action against HAIs and the precise use of our diminishing antimicrobial arsenal.

Conclusion

The threat landscape of HAIs and AMR demands a sophisticated, coordinated response that transcends traditional departmental boundaries. This review underscores that pharmacy-led antimicrobial stewardship, when fully integrated with the real-time intelligence from laboratory diagnostics and radiology, and guided by robust epidemiological tracking under committed health administration oversight, creates a powerful, proactive defense system. This model transforms isolated data into actionable wisdom, moving from reacting to resistant infections to predicting and preventing them. The path forward requires investment, interdisciplinary trust, and institutional will. By forging this integrated partnership, healthcare systems can significantly enhance patient safety, improve outcomes, and safeguard the efficacy of antimicrobials for future generations.

References

1. Alawi, M. M., & Darwesh, B. M. (2016). A stepwise introduction of a successful antimicrobial stewardship program: Experience from a tertiary care university hospital in Western, Saudi Arabia. *Saudi medical journal*, *37*(12), 1350. https://doi.org/10.15537/smj.2016.12.15739
2. Avdic, E., & Carroll, K. C. (2014). The role of the microbiology laboratory in antimicrobial stewardship programs. *Infectious Disease Clinics*, *28*(2), 215-235. https://doi.org/10.1016/j.idc.2014.01.002
3. Banerjee, R., Teng, C. B., Cunningham, S. A., Ihde, S. M., Steckelberg, J. M., Moriarty, J. P., ... & Patel, R. (2015). Randomized trial of rapid multiplex polymerase chain reaction–based blood culture identification and susceptibility testing. *Clinical Infectious Diseases*, *61*(7), 1071-1080. https://doi.org/10.1093/cid/civ447
4. Barlam, T. F., Cosgrove, S. E., Abbo, L. M., MacDougall, C., Schuetz, A. N., Septimus, E. J., ... & Trivedi, K. K. (2016). Implementing an antibiotic stewardship program: guidelines by the Infectious Diseases Society of America and the Society for Healthcare Epidemiology of America. *Clinical infectious diseases*, *62*(10), e51-e77. https://doi.org/10.1093/cid/ciw118
5. Bauer, K. A., Perez, K. K., Forrest, G. N., & Goff, D. A. (2014). Review of rapid diagnostic tests used by antimicrobial

stewardship programs. *Clinical infectious diseases*, *59*(suppl_3), S134-S145. https://doi.org/10.1093/cid/ciu547
6. Blanchette, L., Gauthier, T., Heil, E., Klepser, M., Kelly, K. M., Nailor, M., ... & Outpatient Stewardship Working Group. (2018). The essential role of pharmacists in antibiotic stewardship in outpatient care: an official position statement of the Society of Infectious Diseases Pharmacists. *Journal of the American Pharmacists Association*, *58*(5), 481-484. https://doi.org/10.1016/j.japh.2018.05.013
7. Cassini, A., Högberg, L. D., Plachouras, D., Quattrocchi, A., Hoxha, A., Simonsen, G. S., ... & Hopkins, S. (2019). Attributable deaths and disability-adjusted life-years caused by infections with antibiotic-resistant bacteria in the EU and the European Economic Area in 2015: a population-level modelling analysis. *The Lancet infectious diseases*, *19*(1), 56-66. https://doi.org/10.1016/S1473-3099(18)30605-4
8. Charani, E., Castro-Sánchez, E., Sevdalis, N., Kyratsis, Y., Drumright, L., Shah, N., & Holmes, A. (2013). Understanding the determinants of antimicrobial prescribing within hospitals: the role of "prescribing etiquette". *Clinical Infectious Diseases*, *57*(2), 188-196. https://doi.org/10.1093/cid/cit212
9. Chia, P. Y., Sengupta, S., Kukreja, A., SL Ponnampalavanar, S., Ng, O. T., & Marimuthu, K. (2020). The role of hospital environment in transmissions of multidrug-resistant gram-negative organisms. *Antimicrobial Resistance & Infection Control*, *9*(1), 29. https://doi.org/10.1186/s13756-020-0685-1
10. Doron, S., & Davidson, L. E. (2011, November). Antimicrobial stewardship. In *Mayo Clinic Proceedings* (Vol. 86, No. 11, pp. 1113-1123). Elsevier. https://doi.org/10.4065/mcp.2011.0358
11. Grech, A., Collins, C. E., Holmes, A., Lal, R., Duncanson, K., Taylor, R., & Gordon, A. (2021). Maternal exposures and the infant gut microbiome: a systematic review with meta-analysis. *Gut microbes*, *13*(1), 1897210. https://doi.org/10.1080/19490976.2021.1897210
12. Kuper, K. M., & Hamilton, K. W. (2020). Collaborative antimicrobial stewardship: working with information technology. *Infectious Disease Clinics*, *34*(1), 31-49. https://doi.org/10.1016/j.idc.2019.10.005
13. Lakhani, P., Prater, A. B., Hutson, R. K., Andriole, K. P., Dreyer, K. J., Morey, J., ... & Hawkins, C. M. (2018). Machine learning in radiology: applications beyond image interpretation. *Journal of the American College of Radiology*, *15*(2), 350-359. https://doi.org/10.1016/j.jacr.2017.09.044
14. MacBrayne, C. E., Williams, M. C., Levek, C., Child, J., Pearce, K., Birkholz, M., ... & Parker, S. K. (2020). Sustainability of handshake stewardship: extending a hand is effective years later. *Clinical Infectious Diseases*, *70*(11), 2325-2332. https://doi.org/10.1093/cid/ciz650
15. Maraolo, A. E., Ong, D. S., Cimen, C., Howard, P., Kofteridis, D. P., Schouten, J., ... & Pulcini, C. (2019). Organization and training at national level of antimicrobial stewardship and infection control activities in Europe: an ESCMID cross-sectional survey. *European journal of clinical microbiology & infectious diseases*, *38*(11), 2061-2068. https://doi.org/10.1007/s10096-019-03648-2
16. Messacar, K., Hurst, A. L., Child, J., Campbell, K., Palmer, C., Hamilton, S., ... & Dominguez, S. R. (2017). Clinical impact and provider acceptability of real-time antimicrobial stewardship decision support for rapid diagnostics in children with positive blood culture results. *Journal of the Pediatric Infectious Diseases Society*, *6*(3), 267-274. https://doi.org/10.1093/jpids/piw047
17. Metlay, J. P., Waterer, G. W., Long, A. C., Anzueto, A., Brozek, J., Crothers, K., ... & Whitney, C. G. (2019). Diagnosis and treatment of adults with community-acquired pneumonia. An official clinical practice guideline of the American Thoracic Society and Infectious Diseases Society of America. *American journal of respiratory and critical care medicine*, *200*(7), e45-e67. https://doi.org/10.1164/rccm.201908-1581ST
18. Moehring, R. W., Anderson, D. J., Cochran, R. L., Hicks, L. A., Srinivasan, A., Dodds Ashley, E. S., & Structured Taskforce of Experts Working at Reliable Standards for Stewardship (STEWARDS) Panel. (2017). Expert consensus on metrics to assess the impact of patient-level antimicrobial stewardship interventions in acute-care settings. *Clinical Infectious Diseases*, *64*(3), 377-383. https://doi.org/10.1093/cid/ciw787
19. Morgan, D. J., Malani, P., & Diekema, D. J. (2017). Diagnostic stewardship—leveraging the laboratory to improve antimicrobial use. *Jama*, *318*(7), 607-608. doi:10.1001/jama.2017.8531
20. Nelson, R. E., Hatfield, K. M., Wolford, H., Samore, M. H., Scott, R. D., Reddy, S. C., ... & Baggs, J. (2021). National estimates of

healthcare costs associated with multidrug-resistant bacterial infections among hospitalized patients in the United States. *Clinical Infectious Diseases*, *72*(Supplement_1), S17-S26. https://doi.org/10.1093/cid/ciaa1581
21. Perez, K. K., Olsen, R. J., Musick, W. L., Cernoch, P. L., Davis, J. R., Peterson, L. E., & Musser, J. M. (2014). Integrating rapid diagnostics and antimicrobial stewardship improves outcomes in patients with antibiotic-resistant Gram-negative bacteremia. *Journal of Infection*, *69*(3), 216-225. https://doi.org/10.1016/j.jinf.2014.05.005
22. Poss-Doering, R., Kronsteiner, D., Kamradt, M., Andres, E., Kaufmann-Kolle, P., Wensing, M., ... & Szecsenyi, J. (2021). Antibiotic prescribing for acute, non-complicated infections in primary care in Germany: baseline assessment in the cluster randomized trial ARena. *BMC Infectious Diseases*, *21*(1), 877. https://doi.org/10.1186/s12879-021-06571-0
23. Polidori, P., Vinci, D. L., Adami, S., Bianchi, S., Faggiano, M. E., & Provenzani, A. (2022). Role of the hospital pharmacist in an Italian antimicrobial stewardship programme. *European Journal of Hospital Pharmacy*, *29*(2), 95-100. https://doi.org/10.1136/ejhpharm-2020-002242
24. Rezel-Potts, E., & Gulliford, M. (2023). Electronic health records and antimicrobial stewardship research: a narrative review. *Current Epidemiology Reports*, *10*(3), 132-141. https://doi.org/10.1007/s40471-021-00278-1
25. Rivera, C. G., Mehta, M., Ryan, K. L., Stevens, R. W., Tucker, K. J., & Mahoney, M. V. (2021). Role of infectious diseases pharmacists in outpatient intravenous and complex oral antimicrobial therapy: Society of Infectious Diseases Pharmacists insights. *Journal of the American College of Clinical Pharmacy*, *4*(9), 1161-1169. https://doi.org/10.1002/jac5.1473
26. Sakagianni, A., Koufopoulou, C., Feretzakis, G., Kalles, D., Verykios, V. S., & Myrianthefs, P. (2023). Using machine learning to predict antimicrobial resistance―a literature review. *Antibiotics*, *12*(3), 452. https://doi.org/10.3390/antibiotics12030452
27. Shafiq, N., Praveen Kumar, M., Gautam, V., Negi, H., Roat, R., Malhotra, S., ... & Singh, G. (2016). Antibiotic stewardship in a tertiary care hospital of a developing country: establishment of a system and its application in a unit—GASP Initiative. *Infection*, *44*(5), 651-659. https://doi.org/10.1007/s15010-016-0913-z
28. Silverman, S. G., Lu, D. S., & Lee Jr, F. T. (2016). Abdominal radiology in the era of the Interventional Radiology/Diagnostic Radiology certificate. *Abdominal Radiology*, *41*(4), 586-589. https://doi.org/10.1007/s00261-016-0691-1
29. Thursky, K. A., & Mahemoff, M. (2007). User-centered design techniques for a computerised antibiotic decision support system in an intensive care unit. *International journal of medical informatics*, *76*(10), 760-768. https://doi.org/10.1016/j.ijmedinf.2006.07.011
30. Timbrook, T. T., Morton, J. B., McConeghy, K. W., Caffrey, A. R., Mylonakis, E., & LaPlante, K. L. (2016). The effect of molecular rapid diagnostic testing on clinical outcomes in bloodstream infections: a systematic review and meta-analysis. *Clinical Infectious Diseases*, ciw649. https://doi.org/10.1093/cid/ciw649
31. Tiwari, A., Kurittu, P., Al-Mustapha, A. I., Heljanko, V., Johansson, V., Thakali, O., ... & Heikinheimo, A. (2022). Wastewater surveillance of antibiotic-resistant bacterial pathogens: A systematic review. *Frontiers in microbiology*, *13*, 977106. https://doi.org/10.3389/fmicb.2022.977106
32. Watkins, R. R., & Deresinski, S. (2019). Omadacycline: a novel tetracycline derivative with oral and intravenous formulations. *Clinical Infectious Diseases*, *69*(5), 890-896. https://doi.org/10.1093/cid/ciz242
33. World Health Organization. (2022). *Global antimicrobial resistance and use surveillance system (GLASS) report 2022*. World Health Organization.
34. Xu, J., Huang, J., Yu, Y., Zhou, D., Wang, Y., Xue, S., ... & Li, X. (2022). The impact of a multifaceted pharmacist-led antimicrobial stewardship program on antibiotic use: evidence from a quasi-experimental study in the department of vascular and interventional radiology in a Chinese tertiary hospital. *Frontiers in Pharmacology*, *13*, 832078. https://doi.org/10.3389/fphar.2022.832078