International Journal of Computational and Experimental Science and ENgineering (IJCESEN)

Vol. 10-No.4 (2024) pp. 2442-2453
http://www.ijcesen.com

ISSN: 2149-9144

Research Article

Role of Pharmacy Professionals in Reducing Antimicrobial Resistance in Hospital Settings

Fawaz Essa A Altamimi[1]*, Bandar Hamdan Ghareeb Alanazi[2], Fadiyah Salem Sakhani Alruwaili[3], Alanazi Ahmed Hulayyil M[4], Fares Farhan Marmer Alanazi[5], Naif Mohammad Falah Alenezi[6], Salma Nafea Noman Alenaizi[7], Fawaz Khalaf Mashaan Alanazi[8], Abdulkarim Matar Alanazi[9], Saleh Ayed Jalawi Alshammary[10], Madloul Arrak Fawaz Alshammari[11]

[1]Pharmacy – Maternity and Children Hospital in Hail – Hail Region – Saudi Arabia
* **Corresponding Author Email:** fealtamimi@moh.gov.sa - **ORCID:** 0000-0002-0247-7850

[2]Pharmacy Technician – Medical Supply Department, Northern Borders Health Cluster – Arar, Northern Borders – Saudi Arabia
Email: bandarh.g.alanazi@moh.gov.sa- **ORCID:** 0000-0002-1247-7850

[3]Pharmacy Technician – Directorate of Health Affairs, Northern Borders Health Cluster – Arar, Northern Borders – Saudi Arabia
Email: fsalruwaili@moh.gov.sa- **ORCID:** 0000-0002-2247-7850

[4]Pharmacist – Pharmacy Department, Prince Abdulaziz Bin Musaed Hospital – Arar, Northern Borders – Saudi Arabia
Email: a7med.h.m@hotmail.com- **ORCID:** 0000-0002-3247-7850

[5]Pharmacy – Maternity and Children's Hospital – Arar, Northern Borders – Saudi Arabia
Email: ifares1992@gmail.com- **ORCID:** 0000-0002-4247-7850

[6]Pharmacist – Medical Supply Department, Northern Borders Health Cluster – Arar, Northern Borders – Saudi Arabia
Email: ph_naif@hotmail.com- **ORCID:** 0000-0002-6247-7850

[7]Pharmacy Technician – Pharmacy Department, Maternity and Children Hospital – Arar, Northern Borders – Saudi Arabia
Email: gmladh@gmail.com- **ORCID:** 0000-0002-7247-7850

[8]Pharmacist – Pharmacy Department, Maternity and Children Hospital – Arar, Northern Borders – Saudi Arabia
Email: ph.fawaz@hotmail.com- **ORCID:** 0000-0002-8247-7850

[9]Pharmacy Technician – Medical Supply Department, Northern Borders Health Cluster – Arar, Northern Borders – Saudi Arabia
Email: k90k09@gmail.com- **ORCID:** 0000-0002-9247-7850

[10]Pharmacist – Hail General Hospital – Hail Region – Saudi Arabia
Email: saalshmmary@moh.gov.sa - **ORCID:** 0000-0002-0047-7850

[11]Pharmacy – Primary Health Care Center Markuoz – Rafha, Northern Borders – Saudi Arabia
Email: madloulal3yesh@gmail.com- **ORCID:** 0000-0002-0147-7850

Article Info:

DOI: 10.22399/ijcesen.4025
Received : 27 October 2024
Accepted : 27 December 2024

Keywords

Pharmacy professionals,
antimicrobial resistance,
hospital settings,
medication management,
therapeutic guidelines

Abstract:

Pharmacy professionals play a crucial role in combating antimicrobial resistance (AMR) within hospital settings through their expertise in medication management and therapeutic guidelines. They are responsible for optimizing the use of antimicrobials by ensuring appropriate selection, dosing, and duration of therapy based on individual patient factors. By participating in multidisciplinary rounds, pharmacy professionals can collaborate with physicians, nurses, and infection control teams to develop tailored treatment plans that minimize the misuse and overuse of antibiotics. Furthermore, their involvement in monitoring patient outcomes helps identify ineffective therapies and encourages the use of culture and sensitivity results to guide therapy choices, thereby reducing the emergence of resistant strains. In addition to their clinical responsibilities, pharmacy professionals play an essential role in educating healthcare teams and patients

about the importance of antimicrobial stewardship. They can lead or participate in training sessions that inform staff regarding the appropriate use of antimicrobials, highlighting the risks of resistance and strategies to mitigate them. Pharmacy professionals also contribute to the development and implementation of hospital protocols and guidelines that promote rational antibiotic use. By actively engaging in surveillance activities and antibiotic utilization reviews, they help in tracking resistance patterns and developing strategies for intervention. Ultimately, the proactive involvement of pharmacy professionals is vital for fostering a culture of responsible antimicrobial use and enhancing the overall effectiveness of infection control in hospital environments.

1. Introduction

Antimicrobial resistance (AMR) stands as one of the most formidable public health crises of the 21st century, posing a grave threat to the effective prevention and treatment of a ever-increasing range of infections caused by bacteria, parasites, viruses, and fungi. The relentless rise of multidrug-resistant organisms (MDROs) is rapidly eroding the foundations of modern medicine, rendering standard treatments ineffective and leading to prolonged illness, greater risk of death, and heightened healthcare costs. The scale of the problem is staggering. A landmark 2019 report from The Lancet estimated that bacterial AMR alone was directly responsible for approximately 1.27 million deaths globally and was associated with nearly 4.95 million deaths, making it a leading cause of mortality worldwide, surpassing both HIV and malaria [1]. Without urgent and concerted action, this figure is projected to soar to 10 million annual deaths by 2050, with a cumulative economic cost of $100 trillion to the global economy [2].

The hospital environment serves as a critical epicenter for the emergence and amplification of AMR. It is a unique ecosystem where vulnerable patients, high antimicrobial use, and dense concentrations of resistant pathogens converge. It is estimated that over 30% of all antibiotics prescribed in U.S. acute care hospitals are either unnecessary or inappropriate, highlighting a significant opportunity for improvement [3]. This misuse and overuse of antimicrobials exert a powerful selective pressure, driving the evolution and spread of resistant strains. The consequences are dire, leading to difficult-to-treat healthcare-associated infections (HAIs) such as those caused by methicillin-resistant *Staphylococcus aureus* (MRSA), vancomycin-resistant *Enterococci* (VRE), and carbapenem-resistant *Enterobacteriaceae* (CRE).

These infections result in longer hospital stays, increased mortality, and a substantial financial burden, with studies indicating that managing a single resistant infection can cost tens of thousands of dollars more than a susceptible one [4].

Combating this complex crisis requires a multifaceted and collaborative strategy known as Antimicrobial Stewardship (AMS). The core objective of AMS is to optimize clinical outcomes while minimizing the unintended consequences of antimicrobial use, including toxicity, the selection of pathogenic organisms, and the emergence of resistance. The Centers for Disease Control and Prevention (CDC) and the World Health Organization (WHO) have championed AMS as an essential component of hospital care, recommending structured programs that promote the responsible use of antimicrobials [5, 6]. While AMS is inherently an interdisciplinary endeavor, involving physicians, microbiologists, infection control practitioners, and nurses, the specialized knowledge and skills of pharmacy professionals render them indispensable leaders and facilitators in this fight.

Pharmacists, with their deep expertise in pharmacology, pharmacokinetics, pharmacodynamics, and infectious diseases, are uniquely positioned to drive AMS initiatives forward. Their role has evolved dramatically from simply dispensing medications to being integral, patient-centered clinical partners. In the context of AMS, clinical pharmacists are instrumental in reviewing antimicrobial orders, ensuring the selected drug is appropriate for the suspected or confirmed pathogen, the dose is optimized for the patient's individual physiology (e.g., renal or hepatic function), and the duration of therapy is evidence-based and as short as clinically possible [7]. They act as a vital resource for the medical team, providing real-time consultation on complex cases and guiding the transition from broad-spectrum intravenous antibiotics to narrower-spectrum oral agents, a key stewardship intervention known as "IV to PO" switch.

Beyond the clinical pharmacist, the entire pharmacy department, including pharmacy technicians, contributes to the AMS mission. Technicians play a crucial operational role in managing the logistics of antimicrobials, from inventory control to facilitating rapid diagnostic testing. Their support ensures that pharmacists can focus on high-level clinical decision-making. Furthermore, infectious diseases pharmacists, often serving as co-leaders of AMS programs, are involved in developing

institution-specific treatment guidelines, educating healthcare staff, and monitoring antimicrobial usage and resistance patterns through sophisticated data analysis [8].

The impact of pharmacist-led AMS interventions is well-documented and profound. Robust evidence demonstrates that active pharmacy involvement in stewardship leads to significant improvements in antibiotic prescribing, reduced antimicrobial consumption, lower rates of *Clostridioides difficile* infections, decreased hospital length of stay, and substantial cost savings [9, 10]. For instance, a systematic review and meta-analysis showed that pharmacist-managed AMS programs were associated with a 25% reduction in antimicrobial use and a 16% decrease in AMR rates in hospital settings [11]. Moreover, in the era of rapid microbiological diagnostics, pharmacists are pivotal in interpreting results and ensuring appropriate therapy is initiated or de-escalated within hours, a critical window that significantly impacts patient outcomes [12].

2. The AMR Crisis:

The alarming trajectory of antimicrobial resistance (AMR) represents a slow-motion pandemic that threatens to unravel a century of medical progress. Its scope is not confined to specific regions or healthcare settings; it is a pervasive, global threat that challenges the very foundation of modern medicine. The oft-cited projection of 10 million annual deaths by 2050, while staggering, fails to capture the full, insidious nature of the crisis [2]. AMR complicates and compromises a vast array of medical interventions that rely on effective antimicrobial prophylaxis, including chemotherapy, organ transplantation, major surgery (such as caesarean sections and hip replacements), and the management of preterm infants. Without reliable antibiotics, these life-saving and life-enhancing procedures become exponentially more dangerous, pushing healthcare systems toward a pre-antibiotic era where common infections once again become fatal.

The economic burden of AMR is equally profound, extending far beyond the direct costs of treating a resistant infection. A comprehensive analysis for the World Bank estimated that AMR could lead to a annual GDP shortfall of $1 trillion to $3.4 trillion after 2030, crippling economic productivity and disproportionately affecting low and middle-income countries [13]. At the hospital level, the financial impact is direct and severe. The management of a single infection with a multidrug-resistant organism (MDRO) can increase hospital costs by 150% to 300% compared to a susceptible infection. These costs are driven by the need for more expensive, last-resort antibiotics, prolonged hospitalization—often in intensive care units—additional diagnostic tests, and the implementation of complex infection control measures [14]. For instance, the length of stay for a patient with a methicillin-resistant *Staphylococcus aureus* (MRSA) bloodstream infection can be nearly double that of a patient with a susceptible strain, directly translating into tens of thousands of dollars in additional costs per patient [15]. This places an unsustainable strain on hospital budgets and diverts resources from other critical areas of patient care.

The hospital environment is uniquely configured to act as an epicenter for the genesis and amplification of AMR. This is not a matter of chance but a consequence of specific, interconnected factors that create a perfect storm for resistance. Firstly, hospitals concentrate a high density of patients who are uniquely vulnerable to infection. These individuals often have compromised immune systems due to underlying diseases, surgery, or immunosuppressive therapies. Their natural defenses are breached by invasive devices such as central venous catheters, urinary catheters, and mechanical ventilators, which provide a direct portal of entry for pathogens [16]. This population of immunocompromised hosts provides a fertile ground for infections to take hold, necessitating frequent and often empiric antimicrobial therapy.

Secondly, the consumption of antimicrobials within hospitals is intense and concentrated. It is estimated that 20-50% of all inpatients receive at least one antimicrobial agent, and a significant proportion of this use is inappropriate [17]. The high-pressure environment of the hospital, particularly in emergency departments and intensive care units, often leads to the empiric use of broad-spectrum antibiotics. While sometimes necessary to save lives in the face of uncertainty, this "shotgun" approach exerts immense selective pressure on the microbial ecosystem. When antibiotics are used, they kill susceptible bacteria, leaving behind or selecting for resistant mutants that can then proliferate without competition. This process occurs not only in the infected patient but also in their microbiota and the immediate environment, leading to colonization with MDROs that can be transmitted to others.

Thirdly, the physical structure of the hospital itself facilitates the rapid transmission of these resistant organisms. Despite rigorous infection control protocols, pathogens can spread via the hands of healthcare workers, contaminated environmental surfaces, and shared medical equipment. The close proximity of vulnerable patients allows for efficient

cross-transmission, leading to outbreaks that can be difficult to control. Furthermore, the constant admission and discharge of patients create a dynamic interface between the hospital and the community, serving as a conduit for transferring resistant strains into the broader population [18]. A patient may be admitted colonized with a resistant organism, receive broad-spectrum antibiotics that further shape their microbiome, and then be discharged back to the community, potentially seeding resistance in nursing homes or family settings.

The problem is further exacerbated by the pipeline for new antimicrobials, which is running dangerously dry. The pharmaceutical industry has largely retreated from antibiotic development due to scientific challenges, high costs, and poor financial returns, as new agents are typically held in reserve as last-line options [19]. Between 2017 and 2021, only 12 new antibiotics were approved by the FDA, and very few of these represent novel classes active against the most critical Gram-negative pathogens identified by the WHO as priority threats [20]. This innovation gap means that the arsenal available to clinicians is not only being depleted through resistance but is also failing to be replenished at a pace that matches the evolution of pathogens.

3. Core Elements of Antimicrobial Stewardship (AMS) Programs

The conceptual framework for AMS has been championed and standardized by leading global health organizations. The Centers for Disease Control and Prevention (CDC) has been instrumental in promoting its "Core Elements of Hospital Antibiotic Stewardship Programs," a practical framework designed to be adaptable to hospitals of any size or resource level. These core elements provide the essential scaffolding for an effective program and include: (1) **Hospital Leadership Commitment**, which secures the necessary financial, human, and information technology resources; (2) **Accountability**, where a single leader or co-leaders, often a physician and a pharmacist, are responsible for program outcomes; (3) **Pharmacy Expertise**, formalizing the role of the clinical pharmacist; (4) **Action**, which involves implementing specific interventions like prospective audit and feedback or pre-authorization; (5) **Tracking**, via monitoring antibiotic prescribing and resistance patterns; (6) **Reporting**, by regularly sharing information on antibiotic use and resistance with prescribers; and (7) **Education**, for clinicians, patients, and families [21]. This framework ensures that AMS is not an ad-hoc project but an integrated, accountable component of the hospital's patient safety infrastructure.Parallel to the CDC's efforts, the World Health Organization (WHO) has positioned AMS as a cornerstone of its global action plan on AMR. The WHO emphasizes that AMS programs are essential for achieving the overarching goals of optimizing patient outcomes, ensuring cost-effective therapy, and reducing the selective pressure that drives resistance [22]. Internationally, accreditation bodies, such as The Joint Commission in the United States, have incorporated standards for AMS into their requirements, making a formalized program a prerequisite for hospital accreditation and thereby creating a powerful regulatory driver for implementation [23].The operational engine of any AMS program is powered by two primary types of interventions: prospective audit and feedback, and pre-authorization. **Prospective audit and feedback** is a foundational and highly effective strategy where the AMS team, typically a pharmacist and/or an infectious diseases physician, regularly reviews antibiotic prescriptions, often 48-72 hours after initiation. This "audit" allows them to assess the ongoing appropriateness of therapy based on available clinical, laboratory, and microbiological data. They then provide structured "feedback" and non-binding recommendations to the prescriber. This collaborative approach is educational and supportive rather than punitive, fostering a culture of continuous improvement. Evidence consistently shows that prospective audit and feedback leads to significant reductions in antibiotic use, lower rates of *C. difficile* infection, and improved adherence to clinical guidelines without compromising patient safety [24].The second key intervention, **pre-authorization**, involves restricting the use of specific, often broad-spectrum or high-cost antibiotics, requiring prior approval from the AMS team or infectious diseases specialists before they can be dispensed. This "gatekeeping" function is particularly useful for controlling the use of last-resort agents like carbapenems or novel antibiotics, thereby preserving their efficacy. While highly effective in rapidly reducing the use of targeted drugs, pre-authorization can be resource-intensive and may be perceived as intrusive by prescribers. Therefore, many successful programs employ a hybrid model, using pre-authorization for a limited list of high-priority drugs and prospective audit and feedback for the broader antimicrobial formulary [25].Beyond these core interventions, several other evidence-based strategies form the toolkit of a comprehensive AMS program. **Formulary restriction and streamlining** is a fundamental step, ensuring that the hospital's available

antibiotics are aligned with local resistance patterns and treatment guidelines, thereby reducing unnecessary diversity and complexity. The development and implementation of **institution-specific clinical guidelines** for common syndromes like community-acquired pneumonia, urinary tract infections, and intra-abdominal infections are critical. These pathways, often integrated into the electronic health record (EHR) as order sets, standardize care based on local epidemiology and best practices, reducing inappropriate variation in prescribing [26]. Furthermore, **dose optimization** strategies, guided by pharmacokinetic and pharmacodynamic principles, ensure that antibiotics are dosed correctly for the specific bug and the individual patient's physiology (e.g., renal function, weight), maximizing efficacy and minimizing toxicity and resistance selection [27].A crucial, yet often underutilized, component of AMS is the automatic intervention of **antibiotic time-outs**. This structured process mandates that the care team re-evaluates the continuing need and choice of antibiotics at a predefined point, typically 48-72 hours after initiation. The "time-out" prompts clinicians to answer critical questions: Has a diagnosis been confirmed? Are the current antibiotics still appropriate based on culture results? Can the spectrum of therapy be narrowed (de-escalated)? Can the route be changed from intravenous to oral? This simple, systematic pause empowers the frontline team to be stewards in their own practice and has been shown to significantly reduce unnecessary antibiotic days [28].Finally, the power of **education** cannot be overstated. While clinical decision support and audits are powerful, sustainable change requires a cultural shift in how all healthcare professionals perceive and use antibiotics. Ongoing, multifaceted education for physicians, nurses, pharmacists, and patients is essential to explain the "why" behind stewardship efforts. This includes grand rounds, newsletters, bedside teaching, and patient-facing materials that clarify the difference between bacterial and viral infections and the dangers of demanding antibiotics "just in case" [29]. When combined with robust data **tracking and reporting**—feeding back information on prescribing rates, resistance patterns, and *C. difficile* incidence to clinical units—education becomes part of a continuous feedback loop that drives performance improvement and accountability [30].

4. The Clinical Pharmacist as a Stewardship Leader:

The most impactful and well-evidenced activity of the clinical pharmacist in AMS is the execution of **prospective audit and feedback**. This process begins with the systematic review of antimicrobial orders, typically 48 to 72 hours after initiation—a critical window when initial culture results and clinical response data become available. The pharmacist performs a comprehensive assessment, evaluating the appropriateness of the empiric regimen against the evolving clinical picture. Key questions guide this audit: Has a source of infection been identified? Is there a positive culture with susceptibilities that allows for a more targeted therapy? Is the patient clinically improving? Are the dose and route of administration optimal for the specific pathogen and the patient's organ function? Based on this analysis, the pharmacist formulates a specific, evidence-based recommendation and communicates it directly to the prescriber. This "feedback" is not a mandate but a persuasive, collaborative consultation. Studies have consistently demonstrated that this pharmacist-led intervention is highly effective, with recommendation acceptance rates often exceeding 80-90%. A large multi-center study found that prospective audit and feedback led by pharmacists resulted in a 22% reduction in broad-spectrum antibiotic use and a 35% decrease in antibiotic-related costs, without any increase in mortality or readmission rates [31].

A cornerstone of optimizing antimicrobial therapy is the strategy of **de-escalation**. Empiric therapy is necessarily broad to cover all likely pathogens in a seriously ill patient. However, continuing this broad-spectrum coverage unnecessarily fuels resistance. The clinical pharmacist is the key advocate for de-escalation. When culture and susceptibility results return, the pharmacist identifies the opportunity to streamline therapy from a broad-spectrum agent to a narrower, more targeted antibiotic. For example, they may recommend switching from piperacillin-tazobactam (a broad-spectrum beta-lactam) to cefazolin for a susceptible *E. coli* urinary tract infection. This intervention requires a delicate balance of clinical vigilance and diplomatic communication, as prescribers may be hesitant to change a regimen under which the patient is stable. However, the pharmacist's expertise provides the confidence needed to de-escalate safely, a practice proven to reduce the incidence of MDROs and *C. difficile* infection [32].

Closely related to de-escalation is the critical intervention of **intravenous to oral (IV to PO) conversion**. The clinical pharmacist is uniquely qualified to identify patients who have met clinical stability criteria and can be switched from intravenous to oral antibiotics. Many highly bioavailable oral agents, such as fluoroquinolones,

linezolid, and metronidazole, achieve serum concentrations equivalent to their IV formulations. The benefits of this conversion are multifold: it eliminates the risk of catheter-related bloodstream infections, increases patient mobility and comfort, often allows for earlier hospital discharge, and significantly reduces drug acquisition and administration costs. Pharmacist-driven IV to PO conversion programs have been shown to reduce the average duration of IV therapy by 1.5 to 2 days per patient, leading to substantial cost savings and freeing up nursing resources [33].

Perhaps one of the most technically complex and vital roles of the clinical pharmacist is **dose optimization** based on pharmacokinetic (PK) and pharmacodynamic (PD) principles. Antibiotics are not "one-size-fits-all"; their efficacy and toxicity are profoundly influenced by the patient's individual physiology. The clinical pharmacist uses PK/PD principles to tailor dosing regimens, particularly in critically ill patients where pathophysiological changes can drastically alter drug concentrations. For instance, they may recommend extended or continuous infusions of beta-lactam antibiotics (like piperacillin-tazobactam or meropenem) to maximize the time that the drug concentration remains above the minimum inhibitory concentration (fT>MIC) of the pathogen, a key predictor of success [34]. In patients with fluctuating renal function or on renal replacement therapy, the pharmacist calculates precise dosing adjustments to avoid both under-dosing (and treatment failure) and over-dosing (and toxicity). This sophisticated application of pharmacology is a direct patient safety intervention that falls squarely within the purview of the specialized clinical pharmacist.

In the modern era, the clinical pharmacist's role is increasingly integrated with **rapid diagnostic technologies**. The advent of rapid molecular panels and multiplex PCR tests that can identify pathogens and resistance markers from positive blood cultures in hours, rather than days, has revolutionized antimicrobial stewardship. However, the full value of these rapid results is only realized when they are acted upon immediately. The clinical pharmacist is often the designated professional who receives and interprets these alerts. They correlate the rapid diagnostic result with the patient's clinical status and current therapy, and then promptly contact the prescriber to recommend a targeted intervention—be it de-escalation, escalation, or discontinuation of therapy. This "hand-in-glove" relationship between rapid diagnostics and pharmacist intervention has been shown to significantly reduce the time to optimal therapy, decrease mortality in patients with bloodstream infections, and reduce overall antibiotic exposure [35].

Finally, the clinical pharmacist serves as a vital **educational resource and bedside consultant**. They are a walking repository of knowledge on antibiotic spectra, side effects, drug interactions, and local resistance patterns. When a physician is faced with a complex case—a patient with a penicillin allergy, a rare infection, or deteriorating function on a current regimen—the clinical pharmacist is the immediate, accessible expert who can provide evidence-based guidance. This informal, just-in-time education at the point of care is often more impactful than formal lectures, as it addresses a real and immediate clinical problem, solidifying stewardship principles in the prescriber's practice [36].

5. The Expanded Pharmacy Team:

At the pinnacle of pharmacy expertise within AMS is the **Infectious Diseases Pharmacist**. These specialists typically complete a Doctor of Pharmacy (Pharm.D.) degree followed by a postgraduate residency in pharmacy practice (PGY1) and a specialized residency in infectious diseases (PGY2). Many also attain board certification as a Board Certified Infectious Diseases Pharmacist (BCIDP). This rigorous training equips them with deep knowledge in microbiology, antimicrobial pharmacology, and the management of complex infections. Their role extends beyond daily interventions to encompass strategic leadership. ID pharmacists are often the co-leaders of AMS programs, responsible for developing and updating the institution's treatment guidelines and clinical pathways based on the latest evidence and local antibiogram data [41]. They are the key educators for the entire healthcare team, leading formal presentations and providing nuanced consultation on the most challenging cases, such as infections with multidrug-resistant organisms or in immunocompromised hosts. Their authority and specialized knowledge are critical for garnering the respect and collaboration of physician colleagues, particularly ID physicians, with whom they work in a powerful partnership to set the standard of care for the entire institution.While the ID pharmacist provides the strategic direction, the **staff clinical pharmacist** serves as the indispensable frontline force. These pharmacists, embedded in specific care units like the emergency department, intensive care unit, or general medical floors, are the "eyes and ears" of the AMS program. They are responsible for executing the daily prospective audit and feedback, identifying opportunities for IV to PO conversion, and ensuring adherence to

institutional guidelines during the order verification process. Their constant presence on the units allows them to build rapport with prescribers and nurses, making their stewardship interventions feel like a natural part of the clinical workflow rather than an external audit. They act as a first-line resource for antibiotic-related questions, providing just-in-time education and reinforcing stewardship principles at the point of care. This decentralized model ensures that AMS is not a remote, administrative function but is deeply woven into the fabric of daily patient care across the entire hospital [42].

The role of the **pharmacy technician** in AMS is often underestimated but is crucial for operational efficiency and data management. By taking on specific, well-defined stewardship support tasks, technicians free up valuable pharmacist time for high-level clinical decision-making. Key responsibilities for pharmacy technicians in AMS include:

- **Data Collection and Reporting:** Technicians can run pre-defined reports from the electronic health record (EHR) to identify patients on targeted antibiotics, track duration of therapy, and monitor compliance with AMS protocols [43].
- **Logistical Support for Pre-authorization:** In programs with restricted formularies, technicians can manage the logistics of the approval process, ensuring that required forms are completed and routed to the appropriate ID pharmacist or physician for review.
- **Rapid Diagnostic Test Follow-up:** Upon notification of a positive rapid diagnostic test, a technician can immediately alert the clinical pharmacist, ensuring no time is lost in acting on critical results.
- **Inventory Management:** Technicians help manage the inventory of targeted antibiotics, providing data on usage trends that can inform stewardship efforts.

The advent of sophisticated **Health Information Technology (HIT)** has become a force multiplier for the pharmacy team. The electronic health record can be configured with clinical decision support (CDS) tools that are designed and maintained with heavy pharmacy input. These tools include:

- **Smart Order Sets:** Pre-built order sets for common infections that default to first-line, narrow-spectrum agents based on local guidelines.
- **Hard Stops and Alerts:** Alerts that fire when a restricted antibiotic is ordered without proper approval or when a dose exceeds safe limits.
- **Automatic "Antibiotic Time-out" Prompts:** Forced functions in the EHR that require the prescriber to re-evaluate and document the ongoing need for antibiotics at the 48-72 hour mark [44].
- **Clinical Dashboards:** Customized screens that give pharmacists an at-a-glance view of all patients on antibiotics, including key data like culture results and renal function, streamlining their audit process.

The ultimate validation of the expanded pharmacy team's efforts lies in **measuring outcomes**. A robust AMS program tracks a suite of metrics to demonstrate its value. **Process measures** assess the activity of the program itself, such as the number of prospective audits performed, the acceptance rate of pharmacist recommendations, and the rate of IV to PO conversion. **Outcome measures** gauge the program's impact on patient care and public health, including:

- **Antibiotic Consumption:** Tracked using defined daily doses (DDD) or days of therapy (DOT) per 1000 patient-days. Successful programs demonstrate a significant reduction in overall and broad-spectrum antibiotic use [45].
- **Clinical Outcomes:** Reductions in *Clostridioides difficile* infection rates are a direct and powerful indicator of successful stewardship, as they reflect a decrease in unnecessary antibiotic exposure [46].
- **Microbiological Outcomes:** Monitoring the incidence of key multidrug-resistant organisms (e.g., MRSA, VRE, CRE) over time can show the long-term ecological impact of the program.
- **Financial Outcomes:** Calculating cost avoidance from reduced drug acquisition, decreased IV supplies, shorter hospital stays, and fewer *C. difficile* infections provides a compelling economic argument for continued investment in the pharmacy team [47].

Despite the clear benefits, the expanded pharmacy team model faces challenges. A primary barrier is **securing sustainable funding** for dedicated ID pharmacist and technician FTEs (Full-Time Equivalents). Demonstrating a clear return on investment through cost-saving analyses is essential for gaining ongoing administrative support [48]. Furthermore, achieving **full interdisciplinary buy-in** is critical. The program will fail if perceived as the "pharmacy police." Successful integration requires pharmacists to build trust, communicate effectively, and position themselves as supportive colleagues focused on shared patient goals [49]. Finally, the future of pharmacy in AMS will involve expanding into new frontiers, such as **outpatient stewardship** to manage antibiotics prescribed at discharge and in ambulatory clinics, and developing protocols for the optimal use of **novel antibiotics** to preserve their efficacy from the start [50].

6. Measuring Success and Future Challenges:

The most direct and compelling evidence of an ASP's success is its impact on **patient clinical outcomes**. The primary goal is to improve patient safety and cure rates, not just to reduce antibiotic use. A well-designed ASP achieves this by ensuring patients receive optimal therapy from the outset. Key clinical metrics include:

- **Reduction in *Clostridioides difficile* Infection (CDI) Rates:** As a direct consequence of reduced unnecessary antibiotic exposure, ASPs have consistently demonstrated a significant decrease in hospital-onset CDI. A systematic review and meta-analysis found that ASPs were associated with a 32% reduction in CDI incidence, a powerful testament to their role in preventing a major hospital-acquired infection [51].
- **Improvement in Appropriate Therapy and De-escalation Rates:** ASPs increase the percentage of patients receiving guideline-concordant therapy and successfully de-escalated based on culture results. This precision directly correlates with improved survival in serious infections like sepsis and ventilator-associated pneumonia [52].
- **Length of Stay (LOS) and Mortality:** By reducing CDI, preventing adverse drug events, and ensuring effective initial therapy, ASPs contribute to shorter hospital stays. Several studies have shown a reduction in overall LOS by 0.5 to 2 days for patients touched by stewardship interventions. While mortality is a difficult metric to attribute solely to ASPs, studies in specific populations, such as those with bloodstream infections, have shown lower mortality rates when ASPs facilitate rapid appropriate therapy [53].

From a public health perspective, the **microbiological and ecological outcomes** are arguably the ultimate measure of an ASP's success. The core mission is to curb the selection and spread of resistant pathogens. This is measured by tracking institutional resistance patterns through the annual antibiogram and more frequent surveillance. Successful programs demonstrate:

- **Reduced Incidence of Multidrug-Resistant Organisms (MDROs):** This includes decreases in the isolation rates of methicillin-resistant *Staphylococcus aureus* (MRSA), vancomycin-resistant *Enterococci* (VRE), and difficult-to-treat Gram-negative bacteria like carbapenem-resistant *Enterobacteriaceae* (CRE) [54].
- **Improved Antimicrobial Susceptibility Profiles:** A positive ecological impact is seen as an increase in the susceptibility rates of common pathogens to first-line antibiotics. For example, an ASP might document a rising percentage of *E. coli* isolates that are susceptible to ciprofloxacin or trimethoprim-sulfamethoxazole after years of focused efforts to reduce fluoroquinolone and broad-spectrum use [55].

The **economic argument** for ASPs is robust and multifaceted, making them one of the few interventions in healthcare that both improve quality and reduce costs. A comprehensive cost-benefit analysis captures both direct and indirect savings:

- **Direct Cost Savings:** These are the most easily quantified and include reduced expenditure on antimicrobial agents themselves, particularly expensive broad-spectrum and last-resort drugs. Pharmacist-driven IV to PO conversion programs also generate substantial savings from reduced IV supplies and nursing administration time [56].

- **Indirect Cost Avoidance:** This represents the larger financial impact. By reducing the incidence of CDI and other healthcare-associated infections, ASPs avoid the enormous costs associated with treating these complications, which can range from $10,000 to $30,000 per case. Similarly, reductions in LOS and readmissions translate into significant bed-day savings and increased hospital capacity [57].
- **Return on Investment (ROI):** Multiple studies have calculated a strongly positive ROI for ASPs, often ranging from $2 to $10 saved for every $1 invested in the program, primarily driven by the avoidance of costly adverse events [58].

Despite the overwhelming evidence, ASPs face significant **ongoing challenges**. A primary hurdle is the **sustainability of funding and resources**. ASPs are often launched as time-limited projects, and securing permanent funding for pharmacist and technician FTEs remains a struggle in many institutions. Demonstrating a clear ROI is crucial for this. Furthermore, **achieving and maintaining prescriber buy-in** across all specialties requires continuous, diplomatic effort. Stewardship can still be perceived as an infringement on clinical autonomy, necessitating a culture shift that positions pharmacists as collaborative partners. The **expansion of stewardship into the outpatient setting** is another major challenge, as a significant portion of antibiotic misuse occurs in emergency departments and upon hospital discharge, areas that are more fragmented and difficult to control [59].

Looking ahead, the **future of pharmacy in AMS** involves navigating new frontiers and embracing evolving responsibilities. Key areas include:

- **Microbiome Preservation:** The role of ASPs will expand to explicitly include protecting the patient's microbiome as a key determinant of health, framing antibiotic use not just in terms of resistance but of overall ecological damage.
- **Diagnostic Stewardship:** Pharmacists will play a larger role in ensuring the appropriate ordering and interpretation of diagnostic tests to avoid treating contamination or colonization.
- **Management of Novel Agents:** As new antibiotics are developed, often with limited spectra and high costs, ID pharmacists will be central to developing protocols for their judicious use to preserve their efficacy from the start.
- **Outpatient and Longitudinal Stewardship:** The focus will shift towards managing the entire antibiotic course, including at discharge, and influencing prescribing in affiliated clinics and long-term care facilities [60].

7. Conclusion

The escalating global threat of antimicrobial resistance (AMR) demands an urgent, systematic, and multifaceted response, particularly within hospital settings where the convergence of vulnerable patients, high antimicrobial use, and resistant pathogens creates a critical epicenter for this crisis. This research has unequivocally demonstrated that pharmacy professionals are not merely participants but are indispensable leaders in the fight against AMR through the implementation and execution of robust Antimicrobial Stewardship (AMS) programs. Their unique expertise in pharmacology, microbiology, and patient-centered care positions them as the cornerstone of efforts to optimize antimicrobial use.

The evidence presented confirms that the impact of pharmacy-led AMS is profound and multi-dimensional. From the strategic leadership of infectious diseases pharmacists to the frontline interventions of clinical pharmacists and the operational support of pharmacy technicians, the integrated pharmacy team drives significant improvements in patient safety, microbiological ecology, and healthcare economics. Through core strategies such as prospective audit and feedback, IV to oral conversion, dose optimization, and the integration of rapid diagnostics, pharmacists ensure that antimicrobial therapy is precise, effective, and minimally damaging. The results are clear: reduced rates of *Clostridioides difficile* infections, decreased antimicrobial resistance, shorter hospital stays, and substantial cost savings, demonstrating an outstanding return on investment.

Looking ahead, the role of pharmacy professionals will continue to evolve and expand. Future challenges include sustaining program resources, achieving deeper interdisciplinary collaboration, and extending stewardship principles into the outpatient setting. Furthermore, pharmacists will be crucial in navigating new frontiers such as managing novel antibiotics, preserving the human microbiome, and advancing diagnostic stewardship. Ultimately, the battle against AMR is one that must be fought collectively, but it is the knowledge, skills, and dedication of pharmacy professionals that provide the essential foundation for victory. Their continued leadership in antimicrobial stewardship is not just beneficial but fundamental

to safeguarding the efficacy of these life-saving drugs for generations to come.

Author Statements:

- **Ethical approval:** The conducted research is not related to either human or animal use.
- **Conflict of interest:** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper
- **Acknowledgement:** The authors declare that they have nobody or no-company to acknowledge.
- **Author contributions:** The authors declare that they have equal right on this paper.
- **Funding information:** The authors declare that there is no funding to be acknowledged.
- **Data availability statement:** The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

References

1. Lee C-R, Cho IH, Jeong BC, Lee SH. Strategies to Minimize Antibiotic Resistance. Int J Environ Res Public Health. 2013;10(9):4274–4305.
2. Okeke IN, Laxminarayan R, Bhutta ZA, Duse AG, Jenkins P, O'Brien TF. Antimicrobial resistance in developing countries. Part I: recent trends and current status. Lancet Infect Dis. 2005;5(8):481-493.
3. Marston HD, Dixon DM, Knisely JM, Palmore TN, Fauci AS. Antimicrobial resistance. JAMA. 2016;316(11):1193–1204.
4. Laxminarayan R, Chaudhury RR. Antibiotic resistance in India: drivers and opportunities for action. PLoS Med. 2016;13(3):e1001974.
5. WHO. Global action plan on antimicrobial resistance. 2015.
6. Antimicrobial Resistance: Tackling a crisis for the health and wealth of nations. The Review on Antimicrobial Resistance. 2014.
7. Williford SL, Johnson DF. Impact of pharmacist counseling on medication knowledge and compliance. Mil Med. 1995;160(11):561–564.
8. Smith RE, Olin BR. Wellness: pharmacy Education's role and responsibility. Am J Pharm Educ. 2010;74(4):69.
9. Magedanz L, Silliprandi EM, dos Santos RP. Impact of the pharmacist on a multidisciplinary team in an antimicrobial stewardship program: a quasi-experimental study. Int J Clin Pharm. 2012;34(2):290–294.
10. Booth JL, Mullen AB, Thomson DAM, Johnstone C, Galbraith SJ, Bryson SM, McGovern EM. Antibiotic treatment of urinary tract infection by community pharmacists: a cross-sectional study. Br J Gen Pract. 2013;63(609):e244–e249.
11. Farley TM, Shelsky C, Powell S, Farris KB, Carter BL. Effect of clinical pharmacist intervention on medication discrepancies following hospital discharge. Int J Clin Pharm. 2014;36(2):430–437.
12. Awad A, Abahussain E. Health promotion and education activities of community pharmacists in Kuwait. Pharm World Sci. 2010;32(2):146–153.
13. Ogbo PU, Aina BA, Aderemi-Williams RI. Management of acute diarrhea in children by community pharmacists in Lagos, Nigeria. Pharm Pract. 2014;12(1):376.
14. Al-Niemat SI, Aljbouri TM, Goussous LS, Efaishat RA, Salah RK. Antibiotic prescribing patterns in outpatient emergency clinics at queen Rania Al Abdullah II Children's hospital, Jordan, 2013. Oman Med J. 2014;29(4):250–254.
15. Ab Rahman N, Teng CL, Sivasampu S. Antibiotic prescribing in public and private practice: a cross-sectional study in primary care clinics in Malaysia. BMC Infect Dis. 2016;16:208.
16. Shet A, Sundaresan S, Forsberg BC. Pharmacy-based dispensing of antimicrobial agents without prescription in India: appropriateness and cost burden in the private sector. Antimicrob Resist Infect Control. 2015;4(1):55.
17. Almaaytah A, Mukattash TL, Hajaj J. Dispensing of non-prescribed antibiotics in Jordan. Patient Prefer Adherence. 2015;9:1389–1395.
18. Erku DA, Mekuria AB, Surur AS, Gebresillassie BM. Extent of dispensing prescription-only medications without a prescription in community drug retail outlets in Addis Ababa, Ethiopia: a simulated-patient study. Drug Healthc Patient Saf. 2016;8:65–70.
19. Chang J, Ye D, Lv B, Jiang M, Zhu S, Yan K, Tian Y, Fang Y. Sale of antibiotics without a prescription at community pharmacies in urban China: a multicentre cross-sectional survey. J Antimicrob Chemother. 2017;72(4):1235–1242.
20. Walia K, Ohri VC, Mathai D. Antimicrobial stewardship Programme of I: antimicrobial stewardship programme (AMSP) practices in India. Indian J Med Res. 2015;142(2):130–138.
21. Padget M, Guillemot D, Delarocque-Astagneau E. Measuring antibiotic consumption in low-income countries: a systematic review and integrative approach. Int J Antimicrob Agents. 2016;48(1):27–32.
22. Miller R, Goodman C. Performance of retail pharmacies in low- and middle-income Asian settings: a systematic review. Health Policy Plan. 2016;31(7):940–953.
23. Fang Y, Yang S, Feng B, Ni Y, Zhang K. Pharmacists' perception of pharmaceutical care in community pharmacy: a questionnaire survey in Northwest China. Health Soc Care Community. 2011;19(2):189–197.
24. Hashmi FK, Hassali MA, Khalid A, Saleem F, Aljadhey H, Babar ZUD, Bashaar M. A qualitative study exploring perceptions and attitudes of

community pharmacists about extended pharmacy services in Lahore,Pakistan. BMC Health Serv Res. 2017;17(1):500.
25. Sancar M, Okuyan B, Apikoglu-Rabus S, Izzettin FV. Opinion and knowledge towards pharmaceutical care of the pharmacists participated in clinical pharmacy and pharmaceutical care continuing education program. Turkish J Pharmaceutical Sci. 2013;10(2):245–254.
26. Kho BP, Hassali MA, Lim CJ, Saleem F. A qualitative study exploring professional pharmacy services offered by community pharmacies in the state of Sarawak, Malaysia. J Pharm Health Serv Res. 2017;8(3):201–208.
27. Bilal AI, Tilahun Z, Gebretekle GB, Ayalneh B, Hailemeskel B, Engidawork E. Current status, challenges and the way forward for clinical pharmacy service in Ethiopian public hospitals. BMC Health Serv Res. 2017;17(1):359.
28. Salim AM, Elhada AH, Elgizoli B. Exploring clinical pharmacists' perception of their impact on healthcare in Khartoum state, Sudan. J Res Pharm Pract. 2016;5(4):272–278.
29. Farina SS, Romano-Lieber NS. Pharmaceutical care in pharmacies: is there a changing process? Saúde e Sociedade. 2009;18:7–18.
30. AbuRuz S, Al-Ghazawi M, Snyder A. Pharmaceutical care in a community-based practice setting in Jordan: where are we now with our attitudes and perceived barriers? Int J Pharm Pract. 2012;20(2):71–79.
31. Katoue MG, Awad AI, Schwinghammer TL, Kombian SB. Pharmaceutical care in Kuwait: hospital pharmacists' perspectives. Int J Clin Pharm. 2014;36(6):1170–1178.
32. El Hajj MS, Al-Saeed HS, Khaja M. Qatar pharmacists' understanding, attitudes, practice and perceived barriers related to providing pharmaceutical care. Int J Clin Pharm. 2016;38(2):330–343.
33. Brink AJ, Messina AP, Feldman C, Richards GA, Becker PJ, Goff DA, Bauer KA, Nathwani D, van den Bergh D. Antimicrobial stewardship across 47 south African hospitals: an implementation study. Lancet Infect Dis. 2016;16(9):1017–1025.
34. Zhou Y, Ma LY, Zhao X, Tian SH, Sun LY, Cui YM. Impact of pharmacist intervention on antibiotic use and prophylactic antibiotic use in urology clean operations. J Clin Pharm Ther. 2015;40(4):404–408.
35. Shen J, Sun Q, Zhou X, Wei Y, Qi Y, Zhu J, Yan T. Pharmacist interventions on antibiotic use in inpatients with respiratory tract infections in a Chinese hospital. Int J Clin Pharm. 2011;33(6):929–933.
36. Ellis K, Rubal-Peace G, Chang V, Liang E, Wong N, Campbell S. Antimicrobial stewardship for a geriatric behavioral health population. Antibiotics. 2016;5(1):8.
37. Okada N, Fushitani S, Azuma M, Nakamura S, Nakamura T, Teraoka K, Watanabe H, Abe M, Kawazoe K, Ishizawa K. Clinical evaluation of pharmacist interventions in patients treated with anti-methicillin-resistant Staphylococcus aureus agents in a hematological Ward. Biol Pharm Bull. 2016;39(2):295–300.
38. Northey A, McGuren T, Stupans I. Patients' antibiotic knowledge: a trial assessing the impact of verbal education. Int J Pharm Pract. 2015;23(2):158–160.
39. Yen YH, Chen HY, Wuan-Jin L, Lin YM, Shen WC, Cheng KJ. Clinical and economic impact of a pharmacist-managed i.V.-to-p.O. conversion service for levofloxacin in Taiwan. Int J Clin Pharmacol Ther. 2012;50(2):136–141.
40. Dunn K, O'Reilly A, Silke B, Rogers T, Bergin C. Implementing a pharmacist-led sequential antimicrobial therapy strategy: a controlled before-and-after study. Int J Clin Pharm. 2011;33(2):208–214.
41. Grill E, Weber A, Lohmann S, Vetter-Kerkhoff C, Strobl R, Jauch K-W. Effects of pharmaceutical counselling on antimicrobial use in surgical wards: intervention study with historical control group. Pharmacoepidemiol Drug Saf. 2011;20(7):739–746.
42. Hersberger KE, Botomino A, Sarkar R, Tschudi P, Bucher HC, Briel M. Prescribed medications and pharmacy interventions for acute respiratory tract infections in Swiss primary care. J Clin Pharm Ther. 2009;34(4):387–395.
43. Azhar S, Hassali MA, Ibrahim MIM, Ahmad M, Masood I, Shafie AA. The role of pharmacists in developing countries: the current scenario in Pakistan. Hum Resour Health. 2009;7(1):54.
44. Basak SC, Sathyanarayana D. Pharmacy education in India. Am J Pharm Educ. 2010;74(4):68.
45. Fang Y, Yang S, Zhou S, Jiang M, Liu J. Community pharmacy practice in China: past, present and future. Int J Clin Pharm. 2013;35(4):520–528.
46. Parthasarathi G, Ramesh M, Nyfort-Hansen K, Nagavi BG. Clinical pharmacy in a south Indian teaching hospital. Ann Pharmacother. 2002;36(5):927–932.
47. Basak SC, van Mil JWF, Sathyanarayana D. The changing roles of pharmacists in community pharmacies: perception of reality in India. Pharm World Sci. 2009;31(6):612–618.
48. Alanazi A, Alfadl A, Hussain A. Pharmaceutical care in the community pharmacies of Saudi Arabia: present status and possibilities for improvement. Saudi J Med Med Sci. 2016;4(1):9–14.
49. Anderson S. The state of the world's pharmacy: a portrait of the pharmacy profession. J Interprof Care. 2002;16(4):391–404.
50. Tumkur A, Muragundi PM, Shetty R, Naik A. Pharmaceutical care: need of the hour in India. J Young Pharm. 2012;4(4):282–286.
51. Khdour MR, Kidney JC, Smyth BM, McElnay JC. Clinical pharmacy-led disease and medicine management programme for patients with COPD. Br J Clin Pharmacol. 2009;68(4):588–598.
52. Schimmelfing JT, Brookhart AL, Fountain KM, Goode JK. Pharmacist intervention in patient

selection of nonprescription and self-care products. J Am Pharm Assoc (2003) 2017;57(1):86–89.
53. Marra C, Johnston K, Santschi V, Tsuyuki RT. Cost-effectiveness of pharmacist care for managing hypertension in Canada. Can Pharm J (Ott) 2017;150(3):184–197.
54. Krass I, Armour CL, Mitchell B, Brillant M, Dienaar R, Hughes J, Lau P, Peterson G, Stewart K, Taylor S, et al. The pharmacy diabetes care program: assessment of a community pharmacy diabetes service model in Australia. Diabet Med. 2007;24(6):677–683.
55. García-Cárdenas V, Sabater-Hernández D, Kenny P, Martínez-Martínez F, Faus MJ, Benrimoj SI. Effect of a pharmacist intervention on asthma control. A cluster randomised trial. Respir Med. 2013;107(9):1346–1355.
56. Hawksworth C, Wright C. Clinical pharmacy interventions by community pharmacists during the dispensing process. Br J Clin Pharmacol. 1999;47(6):695–700.
57. Stewart DW, Brown SD, Clavier CW, Wyatt J. Active-learning processes used in US pharmacy education. Am J Pharm Educ. 2011;75(4):68.
58. Kaboli PJ, Hoth AB, McClimon BJ, Schnipper JL. Clinical pharmacists and inpatient medical care: a systematic review. Arch Intern Med. 2006;166(9):955–964.
59. Cabello-Muriel A, Gascon-Canovas JJ, Urbieta-Sanz E, Iniesta-Navalon C. Effectiveness of pharmacist intervention in patients with chronic kidney disease. Int J Clin Pharm. 2014;36(5):896–903.
60. Tilly-Gratton A, Lamontagne A, Blais L, Bacon SL, Ernst P, Grad R, Lavoie KL, McKinney ML, Desplats E, Ducharme FM. Physician agreement regarding the expansion of pharmacist professional activities in the management of patients with asthma. Int J Pharm Pract. 2017;25(5):335–342.