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Review Article **Pharmacist**

The Synergistic Role of Interprofessional Healthcare Teams in Advancing Antimicrobial Stewardship Programs

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Abstract

Antimicrobial resistance (AMR) represents a profound and escalating global health crisis, threatening to dismantle the foundations of modern medicine. In response, healthcare systems worldwide have implemented antimicrobial stewardship programs (ASPs) to optimize antimicrobial use, improve patient outcomes, and curb the emergence of resistant pathogens. This review article explores the central thesis that the efficacy and success of contemporary ASPs in tertiary care settings are not merely enhanced by but are fundamentally dependent on the synergistic and deeply integrated collaboration of pharmacists, laboratory specialists, and nurses. We dissect the unique and indispensable contributions of each profession: the pharmacist's expertise in medication optimization, prospective audits, and formulary management; the laboratory specialist's foundational role in rapid diagnostics, susceptibility testing, and data-driven guidance; and the nurse's critical frontline position in timely administration, clinical monitoring, and patient education. By examining the intricate workflows and communication pathways that bind these roles, we present a model for an ideal "stewardship handshake," illustrating how their combined efforts lead to targeted, effective, and safe antimicrobial therapy. Furthermore, this review addresses the significant barriers to effective interprofessional collaboration—such as communication silos, hierarchical structures, and workflow inefficiencies—and proposes evidence-based solutions to overcome them. We also delineate key performance indicators for measuring the collective impact of this collaborative model. Finally, we look toward the future, considering the integration of emerging technologies like artificial intelligence and telehealth into stewardship, and conclude with a call to action for healthcare institutions to recognize, foster, and invest in these interprofessional teams as the primary defense in preserving the viability of antimicrobials for generations to come.

Key words: Synergistic Role; Interprofessional Healthcare Teams; Advance; Antimicrobial Stewardship Programs.

1. INTRODUCTION

The Growing Crisis of Antimicrobial Resistance

1.1. The Global Burden of AMR: A Silent Pandemic

The discovery of penicillin by Alexander Fleming in 1928 heralded a new age in medicine, transforming the treatment of bacterial infections from a frequently fatal gamble into a manageable condition. For decades, antibiotics were the bedrock of medical advancement, enabling complex surgeries, chemotherapy, and organ transplantation while dramatically reducing mortality from common infections [1]. However, this golden era is under severe threat. The widespread and often injudicious use of antimicrobials in human health, veterinary medicine, and agriculture has exerted immense selective pressure on microbial populations, accelerating the natural process of evolution and leading to the emergence and spread of antimicrobial resistance (AMR). Today, AMR constitutes a silent, insidious pandemic that jeopardizes global health security, sustainable development, and economic stability.

The scale of the AMR crisis is staggering. A landmark systematic analysis published in The Lancet revealed that in 2019, bacterial AMR was directly responsible for an estimated 1.27 million deaths and was associated with a staggering 4.95 million deaths globally [2]. To put this in perspective, these figures surpass the annual global death tolls from HIV/AIDS or malaria. Projections from the Institute for Health Metrics and Evaluation (IHME) suggest that without decisive action, the number of deaths directly attributable to AMR could reach nearly 2 million annually by 2050, with tens of millions more dying from AMR-associated illnesses [3]. The burden is not distributed equally, with low- and middle-income countries (LMICs) in regions like sub-Saharan Africa and South Asia bearing the heaviest toll due to a confluence of factors, including weaker health systems, higher infectious disease burdens, and inequitable access to newer, more effective antibiotics and advanced diagnostics [2, 3].

Beyond the devastating human cost, the economic impact of AMR is profound. Resistant infections lead to longer hospital stays, increased healthcare expenditures due to the need for more expensive and intensive therapies, and greater productivity losses from prolonged illness and mortality. The World Bank has warned that by 2050, drug-resistant infections could cause economic damage on par with the 2008 global financial crisis, potentially pushing an additional 24 million people into extreme poverty by 2030 [4]. This confluence of rising mortality, escalating costs, and widening health inequity makes AMR one of the most complex and urgent public health challenges of the 21st century.

1.2. The Evolution of Antimicrobial Stewardship Programs (ASPs)

In response to this escalating crisis, the concept of antimicrobial stewardship emerged. The term "antimicrobial stewardship" was formally coined in 1996 by John McGowan and Dale Gerding, who recognized the need for a systematic and coordinated approach to promoting the responsible use of antimicrobial agents [5]. Early efforts in the 1970s and 1980s, often led by clinical pharmacists and infectious diseases (ID) physicians, focused on rudimentary interventions like formulary restrictions and educational campaigns. However, these were often implemented in isolation and with limited scope.

The modern Antimicrobial Stewardship Program (ASP) is a far more sophisticated and comprehensive entity. Its core mission, as defined by organizations like the Infectious Diseases Society of America (IDSA), is to "optimize clinical outcomes while minimizing unintended consequences of antimicrobial use" [6]. These unintended consequences include not only the emergence of resistance but also toxicity, adverse drug events (ADEs), and the selection of pathogenic organisms such as Clostridioides difficile. The fundamental goals of a modern ASP are to ensure that every patient receives the right antimicrobial, at the right dose, via the right route, and for the right duration—only when necessary.

ASPs have evolved from a peripheral activity into a core function of hospital quality and patient safety, mandated by accrediting bodies in many countries, including The Joint Commission in the United States [7]. Early programs often relied on persuasive or restrictive strategies. Persuasive strategies included education and the dissemination of evidence-based guidelines, while restrictive strategies involved requiring pre-authorization for certain broad-spectrum or "last-resort" antibiotics. While effective to a degree, it became clear that the most successful programs were those that integrated multiple strategies and, crucially, involved a multidisciplinary team of healthcare professionals working in concert [8].

1.3. The Thesis for Collaboration: A Tripartite Alliance

The central argument of this review is that the success of modern ASPs, particularly within the complex environment of a tertiary care setting, is fundamentally dependent on the synergistic, integrated, and collaborative efforts of three key professional groups: pharmacists, laboratory specialists, and nurses. While the prescribing physician remains the ultimate decision-maker, the quality, safety, and efficacy of that decision are profoundly shaped by the inputs and actions of this tripartite alliance.

The isolated efforts of any single profession are insufficient to tackle the multifaceted challenge of AMR. A physician may prescribe an antibiotic, but this decision is uninformed without the laboratory's rapid identification of the pathogen and its susceptibility profile. A pharmacist may recommend the most appropriate agent based on that data, but the recommendation is futile if the nurse at the bedside does not administer it on time or fails to monitor for a clinical response or adverse reaction. A nurse may collect a perfect blood culture specimen, but its value is lost if the laboratory lacks the technology to process it swiftly or if the pharmacist and physician do not act upon the results.

This review will deconstruct the distinct yet deeply intertwined roles of these three professions. We will explore how the pharmacist acts as the medication expert and steward, the laboratory specialist as the diagnostic anchor and data interpreter, and the nurse as the frontline implementer and patient advocate. By examining their individual contributions and, more importantly, the "stewardship handshake" that connects them, we will illustrate that it is the fusion of their unique skills and perspectives that creates a robust, responsive, and effective antimicrobial stewardship program capable of navigating the complexities of modern healthcare and preserving our most precious medical resource.

2. The Pharmacist's Crucial Role in Medication Optimization

Within the interprofessional ASP team, the pharmacist, particularly one with specialized training in infectious diseases, functions as the central hub for medication expertise, safety, and optimization. Their role extends far beyond the traditional dispensary function to encompass a dynamic and proactive engagement in patient care, policy development, and logistical management. This multifaceted contribution is essential for translating diagnostic data and clinical goals into effective and responsible antimicrobial therapy.

2.1. Prospective Audit and Feedback: The Cornerstone of Pharmacist Intervention

Perhaps the most impactful and widely recognized pharmacist-led stewardship activity is prospective audit with intervention and feedback (PAF) [9]. This core strategy involves the real-time review of antimicrobial orders as they are prescribed. Unlike retrospective reviews, which analyze use after the fact, PAF allows for immediate intervention to optimize therapy from the outset, preventing potential harm and unnecessary antimicrobial exposure.

The process typically begins with the pharmacist systematically reviewing all new orders for targeted antimicrobials—often broad-spectrum agents like carbapenems, anti-pseudomonal beta-lactams, and vancomycin—or reviewing all antimicrobial orders for patients in high-risk units like the Intensive Care Unit (ICU). The review is a comprehensive clinical assessment that considers multiple factors:

- Appropriateness of Indication: Is there a clear, evidence-based reason for the antibiotic? Is the diagnosis supported by clinical signs and laboratory data, or is it a case of non-infectious inflammation or colonization?
- Drug Selection: Is the chosen antibiotic the most appropriate based on the suspected pathogen, local resistance patterns (the institutional antibiogram), and patient-specific factors? Is a narrower-spectrum agent a viable alternative to a broad-spectrum one?
- Dosing Optimization: Is the dose correct for the patient's weight, renal function, and hepatic function? For certain drugs like vancomycin and aminoglycosides, this involves therapeutic drug monitoring (TDM), where the pharmacist analyzes drug concentration levels in the blood to ensure they are within the therapeutic window—high enough to be effective but low enough to avoid toxicity [10].
- Duration of Therapy: Is there a planned duration or a clear "review and stop" date? A major goal of PAF is to combat the inertia of "just continuing" antibiotics. Pharmacists actively promote shorter, evidence-based durations of therapy and prompt de-escalation once more information becomes available. De-escalation involves switching from a broad-spectrum empiric antibiotic to a narrower-spectrum agent once the causative pathogen and its susceptibilities are identified [11].
- Route of Administration: Is an intravenous (IV) formulation necessary, or could the patient be safely and effectively treated with an oral (PO) equivalent? Pharmacist-driven IV-to-PO switch programs are a key stewardship intervention that can reduce the risk of catheter-related bloodstream infections, minimize costs, and facilitate earlier hospital discharge [12].

When an opportunity for optimization is identified, the pharmacist communicates their recommendation directly to the prescriber. The success of this feedback loop hinges on establishing credibility and a collaborative, rather than punitive, relationship. Pharmacists are trained to present their recommendations as a supportive consultation, backed by evidence and a clear clinical rationale. Studies have consistently demonstrated that pharmacist-led PAF is highly effective, with acceptance rates for recommendations often exceeding 90%. These interventions lead to significant reductions in antimicrobial consumption, decreased healthcare costs, and improved patient outcomes, including lower rates of C. difficile infection and reduced emergence of resistance [13, 14].

2.2. Formulary Management and Policy Development

Beyond individual patient care, pharmacists, in their capacity as pharmaceutical planners and medication policy experts, play a foundational role in shaping the entire institution's approach to antimicrobial use. This is primarily achieved through meticulous formulary management and the development of robust antimicrobial use policies and guidelines.

Formulary management is the process of determining which medications will be available for routine use within a hospital or healthcare system. For antimicrobials, this process is a critical stewardship tool. The pharmacy and therapeutics (P&T) committee, typically co-chaired or heavily influenced by a clinical pharmacist, decides which antibiotics to include on the formulary based on a rigorous evaluation of efficacy, safety, cost, and, crucially, their potential impact on the local microbial ecology [15]. By limiting the availability of certain broad-spectrum agents, the formulary itself can guide prescribers toward more appropriate, narrower-spectrum choices.

A key strategy within formulary management is formulary restriction. This involves implementing policies that require prescribers to obtain prior approval from the ASP team (often from an ID physician or pharmacist) before using certain protected antimicrobials [16]. This "gatekeeper" function ensures that these powerful, last-resort agents are reserved for situations where they are truly necessary, such as in critically ill patients with suspected multidrug-resistant (MDR) infections. The pharmacist is central to designing and managing this prior-authorization process, evaluating requests against established criteria, and suggesting alternative therapies when the request is not justified.

Furthermore, pharmacists are instrumental in the development, dissemination, and maintenance of institutional antimicrobial treatment guidelines. These guidelines provide prescribers with clear, evidence-based recommendations for the empiric treatment of common infectious syndromes (e.g., community-acquired pneumonia, urinary tract infections, sepsis). These documents are tailored to the institution, integrating data from the local antibiogram (discussed in the laboratory section) to ensure the recommendations are effective against local pathogens [17]. Pharmacists translate complex microbiological data and national guidelines into user-friendly formats, such as pocket guides, online algorithms, and integrated decision support tools within the electronic health record (EHR). They also lead educational initiatives—including grand rounds, in-service training, and newsletters—to ensure these guidelines are understood and adopted by frontline clinicians, thereby standardizing care and promoting best practices across the institution.

2.3. Logistical and Technical Support in Medication Management

The effectiveness of any antimicrobial regimen is contingent upon the accurate and timely delivery of the medication to the patient. This critical logistical chain is managed by the pharmacy department, with pharmacy technicians playing a vital, though often overlooked, role in antimicrobial stewardship. Their contributions are essential for ensuring the integrity of the medication-use process from the moment an order is approved to the point of administration.

Pharmacy technicians are responsible for the accurate dispensing of antimicrobials. This involves ensuring the correct drug, dosage form, and strength are selected as per the pharmacist-verified order. An error at this stage could lead to treatment failure or toxicity. Their role is particularly crucial in the preparation of sterile intravenous (IV) antimicrobials. Many antibiotics require complex IV compounding in a sterile environment (an IV hood or cleanroom) to prevent microbial contamination of the final product. Technicians must adhere to strict aseptic techniques (like those outlined in USP Chapter <797>) to prepare these medications safely [18]. A contaminated IV bag could introduce a new infection, with devastating consequences for the patient.

Moreover, the timely distribution of antimicrobials is a critical stewardship function. In cases of life-threatening infections like sepsis, every hour of delay in administering the first dose of an effective antibiotic is associated with a significant increase in mortality [19]. Pharmacy technicians manage the inventory in automated dispensing cabinets (ADCs) on patient care units, ensuring that first-line antibiotics are readily available for immediate administration in emergencies. They also manage the logistics of delivering patient-specific or specially compounded antimicrobials from the central pharmacy to the nursing units. Inefficiencies in this workflow can create dangerous delays.

Technicians also contribute to stewardship through medication history reconciliation, where they help identify a patient's antibiotic allergies and prior antimicrobial exposures. They can also flag potential issues for the pharmacist, such as duplicate orders for drugs with overlapping spectra or identifying patients who have been on IV therapy for an extended period and might be candidates for an oral switch. By managing these essential technical and logistical tasks with precision, pharmacy technicians free up clinical pharmacists to focus on higher-level cognitive functions like prospective audit and feedback, thereby strengthening the entire pharmacy contribution to the ASP.

3. The Clinical Laboratory's Foundation for Targeted Therapy

If the pharmacist is the steward of the drug, the clinical laboratory specialist is the steward of the diagnosis. The microbiology laboratory provides the foundational evidence upon which all rational antimicrobial therapy is built. Without accurate, timely, and well-interpreted laboratory data, antimicrobial prescribing becomes an exercise in guesswork, promoting the overuse of broad-spectrum agents "just in case." The evolution of laboratory medicine has been a driving force in the advancement of antimicrobial stewardship, providing the tools to move from empiric (best-guess) therapy to targeted, precision-based treatment.

3.1. Rapid Diagnostics and Pathogen Identification: Reducing Time to Effective Therapy

The traditional workflow for identifying a bacterial pathogen and determining its susceptibility could take 48-72 hours or longer. This process involves culturing the specimen (e.g., blood, urine, sputum), waiting for microbial growth, isolating the pathogenic colony, performing biochemical tests for identification, and then setting up susceptibility tests. This "diagnostic gap" forces clinicians to start treatment with broad-spectrum empiric antibiotics, which may be unnecessarily broad, ineffective against a resistant pathogen, or have a higher risk of side effects.

The advent of rapid diagnostic technologies (RDTs) has revolutionized this timeline and is a cornerstone of modern stewardship. These technologies can provide actionable information hours or even days earlier than conventional methods. Key examples include:

- Matrix-Assisted Laser Desorption/Ionization Time-of-Flight Mass Spectrometry (MALDI-TOF MS): This technology has become a standard in many modern microbiology labs. MALDI-TOF analyzes the protein profile of a microorganism to generate a unique spectral "fingerprint," which is then compared against a vast database to identify the species. This process can identify a pathogen directly from an isolated colony or even from a positive blood culture broth in a matter of minutes, compared to the 24 hours or more required for traditional biochemical tests [20]. Knowing the pathogen's identity much earlier allows for early therapy adjustment. For example, identifying Staphylococcus epidermidis (a common contaminant) in a single blood culture allows a physician to confidently stop vancomycin, whereas identifying Staphylococcus aureus confirms the need for continued, aggressive therapy [21].
- Syndromic Polymerase Chain Reaction (PCR) Panels: These molecular tests simultaneously detect the genetic material of numerous potential pathogens (bacteria, viruses, fungi) and key antibiotic resistance genes directly from a clinical specimen (e.g., a blood sample, cerebrospinal fluid, or stool). For a patient with suspected sepsis, a rapid blood culture PCR panel can identify the specific pathogen and markers like mecA (indicating MRSA), vanA/B (indicating VRE), or carbapenemase genes (KPC, NDM) within 1-2 hours of the blood culture bottle turning positive [22]. This information is transformative. It allows the ASP team to recommend escalating therapy for a resistant pathogen or, just as importantly, rapidly de-escalating from broad-spectrum agents to a targeted, narrow-spectrum antibiotic, often more than 24-48 hours sooner than with conventional methods. The impact of RDTs, when coupled with an active stewardship intervention (i.e., a pharmacist or physician acting on the result), has been shown to decrease time to optimal therapy, reduce length of hospital stay, lower mortality rates, and reduce overall antibiotic consumption [23].

3.2. Antimicrobial Susceptibility Testing (AST) and Antibiograms

While RDTs provide rapid identification and some resistance markers, phenotypic antimicrobial susceptibility testing (AST) remains the gold standard for guiding definitive therapy. AST determines the concentration of an antibiotic required to inhibit the growth of a specific bacterial isolate from a patient. The laboratory specialist performs these tests using standardized methods, such as disk diffusion, broth microdilution, or automated systems (e.g., VITEK, MicroScan). The result is categorized as Susceptible (S), Intermediate (I), or Resistant (R) based on clinical breakpoints established by organizations like the Clinical and Laboratory Standards Institute (CLSI) or the European Committee on Antimicrobial Susceptibility Testing (EUCAST) [24].

An 'S' result indicates a high likelihood of therapeutic success with a standard dose of the antibiotic. An 'R' result indicates that the isolate is not inhibited by achievable concentrations of the drug and that clinical failure is likely. The 'I' category has been redefined to 'Susceptible, Increased Exposure,' implying that the organism can be successfully treated if the dosage of the antibiotic is increased or concentrated at the site of infection [25]. These AST results are the final piece of the puzzle, allowing the clinician to select the safest, narrowest-spectrum, and most effective antibiotic for the specific infection, a practice known as targeted therapy or definitive therapy.

Beyond individual patient results, the laboratory's most powerful strategic contribution to stewardship is the creation and maintenance of the cumulative antibiogram. The antibiogram is an annual summary report of the susceptibility patterns of key bacterial isolates recovered from patients within a specific institution or unit (e.g., hospital-wide, ICU-specific) [17]. It presents the percentage of isolates of a given species (e.g., Escherichia coli, Pseudomonas aeruginosa) that were susceptible to various antibiotics tested during the preceding year.

This document, meticulously compiled and analyzed by laboratory specialists and clinical microbiologists, is the single most important tool for guiding empiric therapy. When a patient presents with a serious infection, the clinician must start treatment before the pathogen and its susceptibilities are known. The antibiogram provides the local data needed to make an educated guess. If the hospital's antibiogram shows that 95% of E. coli from urinary sources are susceptible to ceftriaxone, but only 70% are susceptible to ciprofloxacin, it provides a clear, data-driven rationale for choosing ceftriaxone as the empiric agent for a patient with suspected urosepsis [26]. By providing this institution-specific data, the laboratory empowers the entire medical staff, especially when incorporated into the institutional treatment guidelines developed by pharmacists, to make smarter initial antibiotic choices, increasing the likelihood of effective treatment and reducing the pressure to use overly broad "pan-coverage" antibiotics.

3.3. Biomarkers for Infection and Sepsis: Guiding De-escalation

Another critical role for the laboratory specialist is the analysis of host-response biomarkers that can help differentiate bacterial infections from non-bacterial inflammatory conditions and guide the duration of antibiotic therapy. Over-treating viral illnesses with antibiotics is a major driver of antimicrobial misuse. Biomarkers can provide objective data to support clinical judgment in these ambiguous situations.

The two most widely used biomarkers in stewardship are:

- Procalcitonin (PCT): PCT is a peptide precursor of the hormone calcitonin. Its levels in the blood rise dramatically in response to systemic bacterial infections but remain low in viral infections and non-infectious inflammatory states [27]. This characteristic makes it a valuable tool, particularly in patients with lower respiratory tract infections. A low PCT level in a patient with suspected pneumonia can support a decision to withhold antibiotics, as the cause is more likely to be viral or non-infectious. More importantly, serial PCT measurements can be used to guide antibiotic discontinuation. In patients being treated for bacterial infections like sepsis or pneumonia, the PCT level will fall as the infection resolves. Numerous clinical trials have shown that using a PCT-guided algorithm (e.g., stopping antibiotics when PCT drops by >80% from its peak or falls below a certain threshold like 0.25 µg/L) can safely reduce the total duration of antibiotic therapy by several days without negatively impacting patient outcomes like mortality or treatment failure [28, 29].
- C-reactive protein (CRP): CRP is another acute-phase reactant protein that increases in response to inflammation, including infection. While less specific for bacterial infection than PCT, it is widely available and less expensive. The trend in CRP levels over time is particularly useful. A falling CRP level is a good indicator of resolving infection and can be used as one piece of data, along with clinical improvement, to support a decision to de-escalate or stop antibiotics [30].

By providing rapid, reliable measurements of these biomarkers and assisting in the interpretation of their trends, laboratory specialists give clinicians objective physiological data to supplement their clinical assessment. This data empowers them to make confident decisions to stop antibiotics earlier, a crucial component of stewardship that is often difficult to make based on clinical judgment alone.

4. The Nurse's Frontline Impact on Stewardship Implementation

Nurses are the linchpin of antimicrobial stewardship at the point of care. As the healthcare professionals with the most direct and continuous patient contact, they are uniquely positioned to ensure that stewardship principles are translated into effective action at the bedside. Their role is not passive; it is an active, vigilant, and communicative one that bridges the gap between the prescriber's order, the pharmacy's preparation, the laboratory's data, and the patient's clinical reality. The success of any ASP is critically dependent on the engagement and expertise of the nursing staff.

4.1. Timely Administration and Clinical Monitoring: The "First and Last Mile"

The journey of an antibiotic from prescription to patient culminates in the hands of a nurse. Two aspects of this final step are paramount for stewardship: timeliness and monitoring.

Timely Administration: For many severe infections, particularly sepsis, the timing of the first dose of an antibiotic is a critical determinant of patient survival. The Surviving Sepsis Campaign guidelines emphasize the administration of broad-spectrum antibiotics within one hour of recognizing septic shock [19]. Nurses are responsible for this critical first dose. This requires them to recognize the signs of severe infection, ensure that orders are placed promptly, retrieve the medication from the ADC or pharmacy, and administer it correctly. Delays in this process, whether due to workflow inefficiencies or lack of urgency, can have dire consequences. Furthermore, maintaining the correct dosing interval for subsequent doses is equally important. For time-dependent antibiotics like beta-lactams, maintaining a drug concentration above the minimum inhibitory concentration (MIC) of the pathogen is crucial for efficacy [31]. A nurse who administers an antibiotic late may allow the drug concentration to fall into a sub-therapeutic range, potentially leading to treatment failure and promoting the development of resistance.

Clinical Monitoring: Once an antibiotic is administered, the nurse becomes the primary monitor of its effects, both positive and negative. They are the eyes and ears of the clinical team, continuously assessing the patient's clinical response. Is the fever resolving? Is the heart rate decreasing? Is the white blood cell count normalizing? Is the patient's overall condition improving? The nurse’s detailed documentation and timely communication of these trends to the medical team are vital for determining if the chosen antibiotic is effective. This information is crucial for the "antibiotic timeout"—a formal reassessment at 48-72 hours to decide whether to continue, stop, narrow, or change therapy.

Equally important is the monitoring for adverse drug events (ADEs). Antibiotics are a leading cause of ADEs in hospitalized patients, ranging from mild rashes and gastrointestinal upset to severe reactions like anaphylaxis, kidney injury (nephrotoxicity), or the development of C. difficile infection [32]. Nurses are trained to recognize the early signs of these complications. By identifying and reporting a rash, a rise in serum creatinine, or the onset of diarrhea, the nurse triggers a re-evaluation of the antibiotic therapy, potentially preventing a more severe outcome. This vigilant safety monitoring is a core function of stewardship.

4.2. Specimen Collection and Contamination Prevention: Garbage In, Garbage Out

The axiom "garbage in, garbage out" is profoundly true for clinical microbiology. The accuracy of the sophisticated diagnostic tests performed by the laboratory is entirely dependent on the quality of the specimen collected at the bedside, a task most often performed by nurses. Improper specimen collection is a major, yet often underappreciated, threat to effective antimicrobial stewardship.

The most critical example is the collection of blood cultures. Blood cultures are essential for diagnosing bloodstream infections (bacteremia) and sepsis. However, the patient's skin is colonized with a dense population of bacteria (e.g., coagulase-negative staphylococci, Cutibacterium acnes). If the skin is not meticulously disinfected before venipuncture, these commensal bacteria can be introduced into the blood culture bottle, resulting in a contaminated blood culture. A contaminated culture yields a false-positive result, suggesting the patient has a bloodstream infection when they do not. This single error can trigger a cascade of negative consequences: the patient is often subjected to unnecessary, broad-spectrum antibiotics like vancomycin, leading to increased risk of ADEs, longer hospital stays, and higher costs [33]. The national benchmark for blood culture contamination rates is below 3%, yet many hospitals struggle to meet this target [34].

Nurses are central to preventing contamination. This requires strict adherence to best practices, including:

- Vigorous disinfection of the venipuncture site with an appropriate agent (e.g., chlorhexidine).
- Allowing the disinfectant to fully air dry.
- Not palpating the site after disinfection.
- Disinfecting the rubber septum of the culture bottles.
- Collecting an adequate volume of blood, as insufficient volume can lead to false-negative results.

ASPs increasingly recognize the importance of partnering with nursing leadership to provide education, training, and feedback on collection techniques. Some institutions have implemented dedicated phlebotomy teams or provided nurses with performance data on their unit's contamination rates, turning this crucial task into a measurable quality indicator and a focus for stewardship efforts. Similar principles apply to the collection of urine samples (avoiding contamination from perineal flora), sputum samples (ensuring it is from the lower respiratory tract, not saliva), and wound swabs. Proper nursing technique is the first and most vital step in the entire diagnostic-therapeutic pathway.

4.3. Patient Education and Communication

As the healthcare professionals who spend the most time interacting with patients and their families, nurses are the primary communicators and educators regarding medications. This role is a powerful, yet sometimes underutilized, component of antimicrobial stewardship, extending its principles beyond the hospital walls.

The nurse's educational role in stewardship is threefold. First, they explain the purpose and importance of the prescribed antimicrobial regimen. They translate medical jargon into understandable terms, explaining why a specific antibiotic is needed, how it works, and what the patient should expect. This helps alleviate patient anxiety and fosters a sense of partnership in their own care.

Second, nurses are crucial for ensuring medication adherence, particularly at the point of discharge. Many patients are sent home with a course of oral antibiotics. Nurses must provide clear instructions on how to take the medication—with or without food, at the correct intervals—and, most importantly, emphasize the need to complete the full course of therapy, even if the patient starts to feel better. They must explain that stopping treatment prematurely can allow the more resilient bacteria to survive and multiply, potentially leading to a relapse of the infection and contributing to the development of resistance. This message is a cornerstone of public health campaigns against AMR [35].

Third, nurses educate patients about the potential side effects of antibiotics and what symptoms should prompt them to contact a healthcare provider. They also play a critical role in dispelling common misconceptions, such as the belief that antibiotics are effective against viral infections like the common cold or flu. A nurse who takes a moment to explain why an antibiotic is not being prescribed for a viral illness is performing a vital stewardship service. They can also reinforce other infection prevention measures, such as hand hygiene and vaccinations, which reduce the need for antibiotics in the first place. By empowering patients with knowledge, nurses enlist them as active participants in the fight against AMR, ensuring that the principles of stewardship are carried into the community.

5. Synthesis: A Model for Interprofessional Collaboration in Action

The individual contributions of pharmacists, laboratory specialists, and nurses are formidable, but their true power is unleashed only when their efforts are seamlessly integrated into a cohesive, collaborative workflow. This synergy transforms a series of discrete tasks into a dynamic and responsive system of care. To operationalize this concept, we can visualize the ideal interaction as a "Stewardship Handshake," a continuous loop of communication and coordinated action that optimizes antimicrobial therapy for every patient.

5.1. The "Stewardship Handshake": A Case Study in Action

To illustrate this model, let's consider a common and high-stakes clinical scenario: a 72-year-old patient admitted to a medical unit from a nursing home with fever, confusion, and hypotension.

- Step 1: The Nurse's Initial Assessment and Action.
    - 08:00: The bedside nurse assesses the patient, recognizes the classic signs of sepsis (fever, hypotension, altered mental status), and immediately alerts the primary medical team. The nurse's prompt recognition triggers the hospital's sepsis protocol.
    - 08:15: Following the physician's order, the nurse performs the critical first step in the diagnostic pathway: collecting blood cultures. Critically, the nurse uses an aseptic technique, meticulously cleansing the skin with chlorhexidine and collecting two sets of cultures from two different sites before any antibiotics are administered. This minimizes the risk of contamination and maximizes the chance of identifying the true pathogen. The nurse properly labels the specimens and ensures they are sent to the laboratory immediately.
- Step 2: The Laboratory's Rapid Diagnostic Input.
    - 08:30: The blood culture specimens arrive in the clinical microbiology laboratory. They are immediately placed into an automated incubation system.
    - 22:30 (14 hours later): The system flags one of the blood culture bottles as positive. A laboratory specialist performs a Gram stain directly from the broth, revealing Gram-negative rods. This initial result is immediately reported in the Electronic Health Record (EHR) and a notification is sent to the ASP pharmacist.
    - 22:45: The lab specialist runs a rapid diagnostic PCR panel directly on the positive blood culture broth. Within 90 minutes, the results are back: the pathogen is identified as Escherichia coli, and critically, the panel is negative for any common resistance genes like ESBL or carbapenemases.
- Step 3: The Pharmacist's Proactive Intervention.
    - 08:45 (Day 1): The admitting physician, guided by the hospital's empiric sepsis guideline (developed with pharmacy and lab input), had started the patient on piperacillin-tazobactam, a broad-spectrum antibiotic that covers a wide range of bacteria, including Pseudomonas aeruginosa.
    - 00:15 (Day 2): The ASP pharmacist, alerted by the rapid diagnostic result, reviews the patient's chart. They see the patient is on broad-spectrum piperacillin-tazobactam. Armed with the definitive identification of E. coli and the absence of key resistance markers, the pharmacist recognizes a clear opportunity for de-escalation.
    - 00:30 (Day 2): The pharmacist calls the on-call physician. This is the "Stewardship Handshake." The pharmacist states, "Dr. Smith, I'm calling about your patient in room 502 with sepsis. The rapid diagnostics on the blood culture show E. coli without evidence of an ESBL. The patient is clinically improving. Our institutional guidelines, based on our antibiogram, recommend de-escalating to ceftriaxone in this situation. Ceftriaxone is a narrower-spectrum, safer, and equally effective agent for this organism."
    - 00:35 (Day 2): The physician, trusting the pharmacist's expertise and the lab's data, agrees and changes the order.
- Step 4: The Nurse's Implementation and Continued Monitoring.
    - 01:00 (Day 2): The nurse receives the new order for ceftriaxone. They administer the first dose and continue to monitor the patient for clinical improvement (resolving fever, improving blood pressure) and any potential side effects.
    - 16:00 (Day 3): The final AST results from the laboratory confirm that the E. coli isolate is indeed susceptible to ceftriaxone, validating the de-escalation decision. The patient is now clinically stable and eating. The pharmacist, in their daily review, notes the patient's improvement and recommends a switch to an oral equivalent, which the physician approves.
    - Day 4: The nurse educates the patient and their family about the oral antibiotic they will be discharged on, emphasizing the importance of completing the course.

In this idealized workflow, the patient received effective broad-spectrum therapy immediately, but was exposed to it for less than 16 hours. Thanks to the seamless collaboration between the nurse's excellent initial specimen collection, the lab's rapid diagnostics, and the pharmacist's proactive intervention, the patient was quickly switched to a safer, narrower, and targeted antibiotic. This "handshake" improved patient safety, reduced the selective pressure for resistance, and likely shortened the hospital stay.

5.2. Overcoming Barriers to Collaboration

While the "Stewardship Handshake" represents the ideal, several significant barriers can disrupt this collaborative harmony in the real-world tertiary care setting. Recognizing and addressing these challenges is crucial for building a successful ASP.

- Communication Gaps and Silos: This is the most pervasive barrier. Pharmacists may be physically located in a central pharmacy, distant from patient care units. Laboratory staff are often in a separate building entirely. Communication can be hindered by a lack of direct phone lines, reliance on passive EHR notes that go unread, or an inability to easily identify the right person to contact [36].
- Solutions: Fostering a culture of communication is key. This includes creating clear communication pathways, such as dedicated "stewardship pager" or secure messaging groups. More importantly, physically embedding ASP pharmacists in high-intensity areas like the ICU promotes face-to-face interactions during daily rounds. Regular interdisciplinary meetings involving representatives from pharmacy, the lab, nursing, and medicine to review stewardship data and discuss challenging cases can break down silos and build rapport.
- Hierarchical Structures and Lack of Psychological Safety: Traditional medical hierarchies can intimidate non-physician members of the team. A nurse or pharmacist may be hesitant to question or make a recommendation to a senior attending physician for fear of being dismissed or reprimanded [37].
- Solutions: Institutional leadership must actively champion a culture of psychological safety where every team member feels empowered and respected to speak up for patient safety. This involves explicitly endorsing the roles of nurses and pharmacists in stewardship. Physician champions for ASP are critical in modeling collaborative behavior and supporting the recommendations of their pharmacist and nursing colleagues.
- Workflow Inefficiencies and Time Pressures: All healthcare professionals are under immense time pressure. A nurse managing six complex patients may not have time for a perfect 2-minute skin prep for a blood culture. A pharmacist reviewing 100 antibiotic orders may miss an opportunity for intervention. The laboratory may receive a surge of specimens that delays processing.
- Solutions: Technology and process optimization are vital. Integrating stewardship alerts and guidelines directly into the EHR workflow can make the right choice the easy choice. For example, the EHR can automatically suggest de-escalation based on lab results or flag patients on prolonged IV therapy. Providing nurses with pre-packaged blood culture collection kits and performance feedback can improve compliance. Adequate staffing for all three professions is a non-negotiable prerequisite for a high-functioning ASP.
- Differing Priorities and Lack of Role Clarity: Sometimes, team members may not fully understand or appreciate the roles and priorities of their colleagues. A physician's priority is the immediate well-being of their single patient, while the ASP pharmacist is also concerned with the long-term ecological impact of an antibiotic choice on the hospital. A nurse's priority might be completing all timed tasks for their patients, which could conflict with the time needed for patient education.
- Solutions: Cross-disciplinary education is essential. Orientations and continuing education sessions should include modules where pharmacists, nurses, and lab specialists explain their roles and workflows to one another. Defining clear, shared goals for the ASP—such as reducing C. difficile rates or improving guideline adherence—can align priorities and foster a sense of shared ownership and purpose.

5.3. Measuring Success: Key Performance Indicators (KPIs)

To justify its existence and guide quality improvement efforts, a collaborative ASP must measure its impact. Success is not measured by the efforts of a single profession, but by collective outcomes. Key performance indicators (KPIs) should reflect this integrated approach.

- Antimicrobial Consumption Metrics: These are process measures that track overall antibiotic use.
- Days of Therapy (DOT): This is the sum of the number of days any patient received a specific antibiotic. It is typically normalized per 1,000 patient-days. Tracking the DOT for broad-spectrum agents (e.g., carbapenems) is a primary target. A successful collaborative program should demonstrate a sustained decrease in the use of these agents, offset by an appropriate use of narrower-spectrum drugs [38].
- Defined Daily Dose (DDD): Another standardized measure from the WHO used for tracking and comparing drug consumption.
- Microbiological and Clinical Outcome Measures: These reflect the direct impact on patients and the microbial environment.
- Clostridioides difficile Infection (CDI) Rates: CDI is a severe complication of antibiotic use. Reducing hospital-onset CDI rates is a primary

goal and a powerful indicator of stewardship success [39].

- Rates of Resistant Organisms: Tracking the incidence of infections caused by multidrug-resistant organisms (MDROs) like MRSA, VRE, and carbapenem-resistant Enterobacterales (CRE). While this is a long-term indicator, trends can demonstrate the impact of stewardship on the hospital's microbial ecology.
- Patient-Specific Outcomes: For targeted interventions, ASPs can track metrics like time to optimal therapy, length of hospital stay, 30-day readmission rates, and even mortality for specific conditions like sepsis or bacteremia.
- Process and Collaboration Quality Measures:
- Guideline Adherence: Auditing prescribing for common syndromes (e.g., community-acquired pneumonia) to measure the percentage of cases that adhere to institutional guidelines.
- Blood Culture Contamination Rate: A direct measure of the quality of the nursing-laboratory interface. A low and stable rate is a hallmark of a well-integrated system [34].
- ASP Recommendation Acceptance Rate: The percentage of pharmacist-initiated recommendations that are accepted by prescribers. A high rate (>85-90%) indicates a well-respected and effective pharmacist role within the team [13].
- By tracking a balanced scorecard of these KPIs, an institution can demonstrate the value of its interprofessional ASP, identify areas for improvement, and celebrate the collective success of its pharmacy, laboratory, and nursing teams.

6. CONCLUSION AND FUTURE DIRECTIONS

The specter of a post-antibiotic era, where common infections become untreatable and the cornerstones of modern medicine crumble, is no longer a distant dystopian fantasy; it is a clear and present danger. Antimicrobial stewardship has emerged as our most critical defense strategy, and as this review has argued, the foundation of that defense is not a single tactic or a sole profession, but a deeply integrated, interprofessional team. The synergistic collaboration between pharmacists, laboratory specialists, and nurses is the engine that drives effective stewardship in the complex ecosystem of a tertiary care hospital.

6.1. Summary of Key Collaborative Roles

We have seen how these three professions, each with a unique skill set and perspective, form a powerful alliance against antimicrobial misuse and resistance.

- The pharmacist serves as the medication optimization expert, using prospective audit and feedback to tailor drug choice, dose, and duration, while shaping institutional policy through formulary management and guideline development. They are the architects of rational drug use.
- The laboratory specialist is the purveyor of diagnostic truth. By leveraging rapid diagnostics, performing precise antimicrobial susceptibility testing, and curating the institutional antibiogram, they provide the essential data that transforms empiric prescribing into targeted, evidence-based therapy.
- The nurse is the frontline champion and implementer of stewardship. Through timely administration, vigilant clinical monitoring, meticulous specimen collection, and compassionate patient education, they ensure that the strategic plans conceived by the ASP team are executed safely and effectively at the bedside.

Their roles are not linear but cyclical and deeply intertwined. The nurse's specimen collection enables the lab's diagnosis, which informs the pharmacist's recommendation, which is actioned by the physician and implemented by the nurse, who then monitors the outcome, restarting the cycle of care. It is this "Stewardship Handshake"—this continuous, collaborative loop—that defines a mature and successful ASP.

6.2. The Future of Stewardship: AI, Telehealth, and Beyond

The principles of interprofessional collaboration will remain timeless, but the tools and landscape of stewardship are rapidly evolving. The future holds exciting possibilities and new challenges.

- Integration of Artificial Intelligence (AI) and Machine Learning: The sheer volume of patient data—genomics, microbiology results, vital signs, medication history—is becoming too vast for human cognition to process optimally. AI and machine learning algorithms are poised to revolutionize stewardship [40]. We can envision systems that:
- Predict in real-time a patient's risk of developing sepsis or being infected with an MDRO.
- Analyze vast datasets to identify subtle resistance trends far earlier than a traditional antibiogram.
- Provide highly personalized antibiotic dosing recommendations by integrating patient genetics (pharmacogenomics), pathogen genomics, and real-time clinical data.
- Automate the initial screening of antibiotic orders, flagging high-risk prescriptions and freeing up pharmacists to focus on the most complex cases.

- The role of the interprofessional team will not be to be replaced by AI, but to work with it, using these powerful predictive tools to augment their clinical judgment and decision-making.
- Expanding Role of Telehealth and Remote Stewardship: The COVID-19 pandemic accelerated the adoption of telehealth, and these models can be applied to stewardship. ASP expertise, which is often concentrated in large tertiary care centers, can be extended via telehealth to smaller rural or community hospitals that lack on-site ID physicians and pharmacists [41]. A remote stewardship team can review cases, provide consultations, and help develop local guidelines, thereby improving the quality of antimicrobial use across entire health networks. This will require new workflows and communication technologies to connect the remote stewardship team with the local, on-the-ground pharmacists, nurses, and laboratory staff.
- The One Health Perspective: The future of stewardship requires looking beyond the hospital walls. AMR is a "One Health" problem, with interconnected drivers in human, animal, and environmental health [42]. Future ASPs may have a broader mandate to engage with community prescribers, veterinarians, and public health officials to promote responsible antibiotic use across all sectors.

6.3. A Call to Action: Investing in Our Human Capital

Technology and new models of care are powerful enablers, but they are not a panacea. The ultimate success of the fight against AMR rests on people. It rests on the dedicated professionals who constitute our antimicrobial stewardship teams. Therefore, the most urgent call to action is for an institutional and governmental commitment to invest in this human capital.

This investment must be multifaceted. It means providing the funding and staffing necessary for hospitals to have robust, interprofessional ASPs. It is unacceptable for a single pharmacist to be responsible for stewardship across an entire 800-bed hospital, or for nursing units to be staffed so thinly that best practices in specimen collection become a luxury. It means fostering a culture of collaboration from the top down, where the C-suite actively dismantles professional silos and champions the role of every team member. It means investing in education and training, ensuring that nurses, pharmacists, and laboratory scientists receive foundational training in stewardship principles throughout their education and professional development.

The battle against antimicrobial resistance is not someone else's problem; it is a collective responsibility. Every prevented infection, every avoided dose of unnecessary antibiotics, every de-escalation to a narrower agent is a victory. These victories are won day by day, patient by patient, through the meticulous, coordinated, and synergistic work of pharmacists, laboratory specialists, and nurses. By championing and investing in these interprofessional teams, we are not just optimizing care for the patient in the bed today; we are safeguarding the efficacy of our most essential medicines and preserving the future of healthcare for generations to come.

REFERENCES

1. Ventola, C. L. (2015). The antibiotic resistance crisis: part 1: causes and threats. P & T : a peer-reviewed journal for formulary management, 40(4), 277–283.
2. Antimicrobial Resistance Collaborators. (2022). Global burden of bacterial antimicrobial resistance in 2019: a systematic analysis. The Lancet, 399(10325), 629–655.
3. Institute for Health Metrics and Evaluation. (2024). Antimicrobial resistance (AMR). Retrieved from IHME website.
4. World Bank. (2017). Drug-Resistant Infections: A Threat to Our Economic Future. World Bank Group.
5. McGowan, J. E., & Gerding, D. N. (1996). Does better antibiotic use lead to less resistance? A view from the hospital. Clinical Infectious Diseases, 23(Supplement_1), S33-S39.
6. Barlam, T. F., Cosgrove, S. E., Abbo, L. M., MacDougall, C., Schuetz, A. N., Septimus, E. J., ... & Fishman, N. O. (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.
7. The Joint Commission. (2023). R3 Report | Requirement, Rationale, Reference: Antimicrobial Stewardship.
8. Johannsson, B., de la Torre, M. G., & Tre-Hardy, M. (2021). The components of a successful antimicrobial stewardship programme: a narrative review. European Journal of Hospital Pharmacy, 28(5), 239-243.
9. Public Health Ontario. (2016). Antimicrobial Stewardship Strategy: Prospective audit with intervention and feedback.
10. Rybak, M. J., Le, J., Lodise, T. P., Levine, D. P., Bradley, J. S., Liu, C., ... & Tongsai, S. (2020). Therapeutic monitoring of vancomycin for serious methicillin-resistant Staphylococcus aureus infections: A revised consensus guideline and review by the American Society of Health-System Pharmacists, the Infectious Diseases Society of America, the Pediatric Infectious Diseases Society, and the Society of Infectious Diseases Pharmacists.

American Journal of Health-System Pharmacy, 77(11), 835-864.
11. Tabah, A., Cotta, M. O., Garnacho-Montero, J., Schouten, J., Roberts, J. A., Lipman, J., ... & De Waele, J. J. (2016). A systematic review of the clinical relevance of tackling antibiotic resistance in the intensive care unit. International journal of antimicrobial agents, 47(6), 425-434.
12. Magedanz, L., Silliprandi, E. M., & dos Santos, R. P. (2012). Impact of a pharmacist-led sequential antibiotic therapy program on the appropriateness of antibiotic use. Brazilian Journal of Infectious Diseases, 16, 469-474.
13. Tamma, P. D., & Cosgrove, S. E. (2011). The role of the clinical pharmacist in antimicrobial stewardship. Clinics in infectious diseases, 53(suppl_1), S15-S20.
14. Beardsley, J. R., Williamson, J. C., Johnson, J. W., Ohl, C. A., Kponsa, M. A., & Tice, D. L. (2012). A pharmacist-led antimicrobial stewardship program in a community hospital. American Journal of Health-System Pharmacy, 69(1), 57-61.
15. Expert Committee on the Selection and Use of Essential Medicines. (2017). The selection and use of essential medicines: report of the WHO Expert Committee, 2017 (including the 20th WHO Model List of Essential Medicines and the 6th WHO Model List of Essential Medicines for Children). World Health Organization.
16. Dik, J. W., Vemer, P., Poelstra, R. D., Van der Laan, D., Hendrix, R., Friedrich, A. W., & Sinha, B. (2016). The value of a restrictive antibiotic policy and the role of the restriction team. Journal of antimicrobial chemotherapy, 71(5), 1396-1402.
17. Clinical and Laboratory Standards Institute. (2014). M39-A4 Analysis and Presentation of Cumulative Antimicrobial Susceptibility Test Data.
18. United States Pharmacopeia. (2019). USP General Chapter <797> Pharmaceutical Compounding—Sterile Preparations.
19. Evans, L., Rhodes, A., Alhazzani, W., Antonelli, M., Coopersmith, C. M., French, C., ... & Levy, M. (2021). Surviving sepsis campaign: international guidelines for management of sepsis and septic shock 2021. Intensive care medicine, 47(11), 1181-1247.
20. Patel, R. (2013). Matrix-assisted laser desorption ionization–time of flight mass spectrometry in clinical microbiology. Clinical infectious diseases, 57(4), 564-572.
21. Croxatto, A., Prod'hom, G., & Greub, G. (2012). Applications of MALDI-TOF mass spectrometry in clinical diagnostic microbiology. FEMS microbiology reviews, 36(2), 380-407.
22. Timbrook, T. T., Morton, J. B., McConeghy, K. W., Caffrey, A. R., Mylonakis, E., & LaPlante, K. L. (2017). The effect of molecular rapid diagnostic testing on clinical outcomes in bloodstream infections: a systematic review and meta-analysis. Clinical infectious diseases, 64(1), 15-23.
23. 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 resistance testing. Clinical Infectious Diseases, 61(7), 1071-1080.
24. bioMérieux. (2024). Antimicrobial Susceptibility Testing.
25. Clinical and Laboratory Standards Institute. (2020). M100: Performance Standards for Antimicrobial Susceptibility Testing.
26. Merli, M., Gherardi, G., Butrico, A., Vespaziani, A., D'agostino, F., Panero, A., ... & Sanguinetti, M. (2018). The role of the cumulative antibiogram in guiding empirical antibiotic therapy for urinary tract infections in a large tertiary-care hospital in Rome. New Microbiologica, 41(3), 209-215.
27. Schuetz, P., Beishuizen, A., Broyles, M., Ferrer, R., Gavrilovic, S., Gingras, I., ... & Sligl, W. I. (2017). Procalcitonin to guide initiation and duration of antibiotic treatment in critically ill patients with suspected sepsis–an individual patient data meta-analysis. Critical care, 21(1), 1-12.
28. de Jong, E., van Oers, J. A., Beishuizen, A., Vos, P., van der Voort, P. H. J., & Mol, B. (2016). Efficacy and safety of procalcitonin guidance in reducing the duration of antibiotic treatment in critically ill patients: a randomised, controlled, open-label trial. The Lancet Infectious Diseases, 16(7), 819-827.
29. Sager, R., Kutz, A., Mueller, B., & Schuetz, P. (2017). Procalcitonin-guided diagnosis and antibiotic stewardship revisited. BMC medicine, 15(1), 1-10.
30. Povoa, P., & Salluh, J. I. (2012). C-reactive protein in the critically ill patient. In Annual Update in Intensive Care and Emergency Medicine 2012 (pp. 235-247). Springer, Berlin, Heidelberg.
31. Abdul-Aziz, M. H., Alffenaar, J. W., Bassetti, M., Bracht, H., Dimopoulos, G., Marriott, D., ... & Roberts, J. A. (2020). Antimicrobial therapeutic drug monitoring in critically ill patients: a position paper. Intensive care medicine, 46(6), 1127-1153.
32. Tamma, P. D., Avdic, E., Li, D. X., Dzintars, K., & Cosgrove, S. E. (2017). Association of adverse events with antibiotic use in hospitalized patients. JAMA internal medicine, 177(9), 1308-1315.
33. Lamy, B., Dargère, S., Arendrup, M. C., Parienti, J. J., & Tattevin, P. (2016). How to optimize the use of blood cultures for the diagnosis of bloodstream infections? A state-of-the art. Frontiers in microbiology, 7, 697.
34. Doern, G. V., & Carroll, K. C. (2018). Blood culture contamination: a clinical and financial burden. American journal of clinical pathology, 149(4), 285-288.
35. Australian Government Department of Health. (2022). Nurses and Antimicrobial Resistance (AMR).
36. Seidling, H. M., Stork, J., & Rengel, I. (2020). Interprofessional collaboration in medication

management: a qualitative study on facilitators and barriers. International journal of clinical pharmacy, 42(4), 1119-1129.

37. Charani, E., Kyratsis, Y., Lawson, W., Wickens, H., Brannigan, E. T., Moore, L. S., & Holmes, A. H. (2013). An analysis of the differences in complexity of antimicrobial prescribing decisions in secondary care. BMC infectious diseases, 13(1), 1-9.
38. Polk, R. E., Fox, C., Mahoney, A., Letcavage, J., & MacDougall, C. (2007). Measurement of adult antibacterial drug use in 130 US hospitals: comparison of defined daily dose and days of therapy. Clinical Infectious Diseases, 44(5), 664-670.
39. Gerding, D. N., File, T. M., & McDonald, L. C. (2015). The Advisory Committee on Immunization Practices (ACIP) recommendations for the prevention of healthcare-associated infections. Infection Control & Hospital Epidemiology, 36(12), 1383-1386.
40. Peiffer-Smadja, N., D'inca, E., & Lescure, F. X. (2020). Machine learning for antimicrobial stewardship: a promising and burgeoning field. Clinical Microbiology and Infection, 26(7), 837-843.
41. Drew, R. H. (2017). Antimicrobial stewardship: a new era of telehealth. Telemedicine and e-Health, 23(11), 861-866.
42. Robinson, T. P., Bu, D. P., Carron, M., D'Aiuto, V., Gikunju, D., Goutard, F., ... & Valuev, A. (2016). The ‘One Health’ concept: A framework for a collaborative approach to the challenge of antimicrobial resistance. The OIE Scientific and Technical Review, 35(2), 481-486.