Antimicrobial Stewardship Programs

**Dang Trung Kien #**

Department of Pathobiology

School of Integrative Biology

University of Illinois Urbana-Champaign

Urbana, IL 61801, USA

Laboratory Department

Vinmec International Hospital

Hai Ba Trung District

Hanoi 100000, Vietnam

[v.kiendt13@vinmec.com](mailto:v.kiendt13@vinmec.com)

**Nguyen Thi Thu Ha**#

Bacteriology and Hygiene Department

Pitié-Salpêtrière Hospital,

APHP and Sorbonne Université

Paris 75651, France

[thithuha.nguyen@aphp.fr](mailto:thithuha.nguyen@aphp.fr)

**Andrew W. Taylor-Robinson**\*

College of Health Sciences

VinUniversity

Vinhomes Ocean Park

Gia Lam District

Hanoi 100000, Vietnam

[andrew.tr@vinuni.edu.vn](mailto:andrew.tr@vinuni.edu.vn)

Center for Global Health

Perelman School of Medicine

University of Pennsylvania

Philadelphia, PA 19104, USA

# Contributed equally. \* Corresponding author.

**ABSTRACT**

Antimicrobial stewardship programs (ASPs) are structured initiatives aimed at optimizing the use of antimicrobials to improve patient outcomes, reduce adverse effects, and combat the rise of antimicrobial resistance. These programs involve a multidisciplinary approach, engaging healthcare professionals such as physicians, nurses, pharmacists, and infection control specialists to implement evidence-based practices in prescribing and managing antibiotics to combat pathogenic bacterial infections effectively in hospitals and in the community. Key components of ASPs include monitoring antibiotic prescribing patterns, providing education on appropriate antimicrobial use, and promoting adherence to clinical guidelines. Research indicates that effective ASPs can lead to significant improvements in clinical outcomes, including reduced rates of infection and reinfection associated with antibiotic use. This is particularly relevant to infections, such as with *Clostridioides difficile*, that are considered difficult to treat primarily because of their resistance to existing antibiotic regimens, thereby leading to high recurrence rates. Furthermore, initiatives like antibiotic allergy de-labeling have been recognized as beneficial for enhancing antimicrobial stewardship by allowing for more appropriate antibiotic selections. Despite the proven benefits, challenges remain, particularly in resource-limited settings where the implementation of ASPs may be hindered by a lack of trained personnel and infrastructure. Overall, the establishment and maintenance of ASPs are critical in the global effort to preserve the efficacy of existing antimicrobials and to ensure safe, effective patient care. This chapter discusses the rationale, structure, implementation, and monitoring of current ASPs, including diagnostic microbiology issues but also human factors relating to healthcare professionals, workplace training, and leadership. Obstacles and opportunities on the path towards optimization of this increasingly important clinical microbiology tool are highlighted.

**Keywords:** antibiotic; antimicrobial resistance; antimicrobial stewardship; antibiotic; clinical microbiology; patient care; treatment guidelines

**Abbreviations:** access, watch, reserve, AWaRe; antimicrobial consumption, AMC; antimicrobial resistance, AMR; antimicrobial stewardship, AMS; antimicrobial stewardship program, ASP; artificial intelligence, AI; community-acquired pneumonia, CAP; *Clostridioides difficile* infection, CDI; days of therapy, DOT; defined daily dose, DDD; electronic health record, EHR; high-income country, HIC; Infectious Diseases Society of America, IDSA; intensive care unit, ICU; intravenous, IV; low- and middle-income country, LMIC; methicillin-resistant *Staphylococcus aureus*, MRSA; minimum inhibitory concentration, MIC; Pharmacy and Therapeutics, P&T; prospective audit and feedback, PAF; skin and soft tissue infection, SSTI; therapeutic drug monitoring, TDM; urinary tract infection, UTI; US National Healthcare Safety Network; NHSN; World Health Organization, WHO.

1. **introduction**

Antimicrobial resistance (AMR) is one of the greatest public health threats to all societies, responsible for significant morbidity and mortality globally. It directly causes an estimated 5 million human deaths per year, with many more indirect, with associated increased healthcare costs, prolonged hospital stays, and poor patient outcomes. Specifically, antibiotic resistance not only affects treatment of bacterial diseases, which are common in low- and middle-income countries (LMICs), but also treatment of chronic diseases and the success of complex medical therapies in high-income countries (HICs), such as organ transplantation and cancer chemotherapy [1].

Antibiotic resistance is, by its very nature, a consequence of microbial evolution. Therefore, it is not the outcome of a single behavioral change but rather the result of microorganisms’ interactions with us, with other species, and with their environment. However, the emergence and rise of this phenomenon can be most clearly observed in the medical environment. The inappropriate prescribing of antibiotics involving errors in drug selection, dosing, duration, or unnecessary use is an important risk factor for this resistance. To illustrate this, at least 30% of all antibiotics prescribed in acute care hospitals and through outpatient antibiotic prescriptions in the USA are either unnecessary or suboptimal [2, 3]. Patients who are unnecessarily exposed to antibiotics are placed at risk of adverse events with no benefit. The misuse of antibiotics can adversely impact the health of patients who are not even exposed to them via the spread of resistant microorganisms, exemplified by *Clostridioides difficile* [4].

Tackling the problem of antibiotic resistance is complex and requires comprehensive coordination across multiple levels and sectors. In medical practice, in particular, the limited availability of early detection methods for antibiotic resistance and the delay in developing new antibiotics means that the initial choice of appropriate antibiotics is almost entirely based on empirical therapy and local availability. Furthermore, even if improved diagnostic techniques and novel antibiotics become available in the future, without coordinated management and intervention measures antibiotic resistance will rapidly re-emerge. To this end, antimicrobial stewardship (AMS) aims to optimize the benefits of treatment while limiting the harm of antibiotics by ensuring that they are prescribed only when necessary and with the appropriate drug, dose, and duration. Stewardship programs are applicable across all healthcare settings and play a critical role in enhancing patient safety, slowing the spread of bacterial resistance, and preserving the effectiveness of these essential medications for future generations.

1. **Structure of Antimicrobial Stewardship Programs**
2. *ASP structure*

Several guidelines have been issued by different national governments and peak professional bodies in an effort to combat the growing global phenomenon of antibiotic resistance (Table 1). The World Health Organization (WHO) has issued a detailed practical toolkit for developing an antimicrobial stewardship program (ASP) in healthcare facilities in low- and middle-income countries in 2019, and then in 2021, a practical guide for 10 common interventions to promote the optimal use of antimicrobials in healthcare facilities [5, 6]. The US Centers for Disease Control and Prevention also developed the core elements for an ASP based on existing guidelines, as well as recommendations from US health organizations such as the Infectious Diseases Society of America, Society for Healthcare Epidemiology of America, American Society of Health System Pharmacists, Society of Infectious Diseases Pharmacists, and The Joint Commission [7, 8]. Other global governments and health systems have instigated their own ASP along similar lines. Given the complex nature of AMR, an effective ASP must be implemented at multiple levels and across multiple components. However, in reality, there is no one-size-fits-all structure; instead, a program needs to be tailored to local resources and characteristics.

**Table 1: Guidelines for antimicrobial stewardship by government and non-government organizations.**

|  |  |  |
| --- | --- | --- |
| **Organization/Institution** | **Guidelines** | **Source** |
| World Health Organization | Antimicrobial stewardship programs in healthcare facilities in low- and middle-income countries | https://iris.who.int/bitstream/handle/10665/329404/9789241515481-eng.pdf |
| World Health Organization | Antimicrobial stewardship interventions: a practical guide | https://iris.who.int/bitstream/handle/10665/340709/9789289054980-eng.pdf |
| US Centers for Disease Control and Prevention | Core elements of hospital antibiotic stewardship programs | https://www.cdc.gov/antibiotic-use/hcp/core-elements/hospital.html |
| Infectious Diseases Society of America & Society for Healthcare Epidemiology of America | Implementing an antibiotic stewardship program | https://www.idsociety.org/practice-guideline/implementing-an-ASP/ |
| The Joint Commission | New and revised requirements for antibiotic stewardship | https://www.jointcommission.org/-/media/tjc/documents/standards/r3-reports/r3\_antibioticstewardship\_july2022\_final.pdf |
| European Society of Clinical Microbiology and Infectious Diseases (ESCMID) | Guidelines for antimicrobial stewardship in emergency departments | https://www.clinicalmicrobiologyandinfection.com/article/S1198-743X%2824%2900251-9/fulltext |
| UK National Health Service | Antimicrobial stewardship: start smart then focus | https://www.gov.uk/government/publications/antimicrobial-stewardship-start-smart-then-focus |
| Australian Commission on Safety and Quality in Health Care | Antimicrobial stewardship clinical care standard | https://www.safetyandquality.gov.au/our-work/antimicrobial-stewardship/antimicrobial-stewardship-clinical-care-standard |
| Public Health Agency of Canada | Antimicrobial stewardship framework | https://www.phn-rsp.ca/en/docs/antimicrobial-stewardship.pdf |
| Ministry of Health, South Africa | National antimicrobial stewardship program | https://www.fidssa.co.za/federation-members/saasp-mission |
| Pan American Health Organization | Recommendations for implementing antimicrobial stewardship programs in Latin America and the Caribbean | https://iris.paho.org/bitstream/handle/10665.2/49645/9789275120408\_eng.pdf |
| Ministry of Health, Japan | Manual of antimicrobial stewardship, 3rd edition | https://www.mhlw.go.jp/content/10900000/001265278.pdf |
| Federal Ministry of Health, Germany | Dart 2030 – German antimicrobial resistance strategy | https://www.bundesgesundheitsministerium.de/en/themen/praevention/antibiotika-resistenzen/dart-2030.html |
| Ministry of Health, Singapore | National strategic action plan on antimicrobial resistance | https://isomer-user-content.by.gov.sg/3/ec041487-3354-4a03-955c-0f2503cfaf83/national-strategic-action-plan-on-amr-progress-report-2018-2020.pdf |
| National Health Commission, China | National action plan to contain antimicrobial resistance (2022-2025) | https://cdn.who.int/media/docs/default-source/antimicrobial-resistance/amr-spc-npm/nap-library/china-national-action-plan-on-amr-(2022-2025)---eng.pdf?sfvrsn=e3bf8980\_4 |

At the national or state level, authorities need to recognize AMS as a priority, allocate resources to short-term and/or long-term goals, and develop policies to apply to relevant facilities. Policies should be based on local conditions, so priorities and implementation steps may require flexibility. For example, information on local antibiotic availability, AMR patterns, and empirical treatment practices should be considered when preparing user guidelines for antimicrobial treatments. Where national AMR databases do not exist or empirical treatment guidelines are inconsistent, they should be carefully assessed, developed and implemented in order to ensure consistency and relevance. In addition to policies, national ASPs must include public awareness campaigns and promote increased understanding of antibiotic resistance among both the general public and healthcare workers. Community outreach is an important but challenging aspect of scaling up ASPs. Reported data on the overuse of antibiotics in hospitals in HICs such as in Europe and North America indicate that it is not a straightforward task to change the antibiotic use habits of healthcare workers, who have an assumed higher level of knowledge compared to a lay person. To attain a good database for surveillance of antibiotic resistance and to optimize the use of antibiotics in treatment, it is necessary to develop and improve laboratory capacity in healthcare facilities. Investment in modern testing techniques (such as now used in diagnostic microbiology, genotyping and imaging) should be supported by governments because some procedures require high-grade facilities that bring little economic benefit to the hospital or are not evaluated properly for their importance to diagnosis and treatment.

The implementation of an ASP in healthcare facilities should be part of a national program that further specifies structures, actions, and monitoring to fit the operation. Although called differently in various guides, they are essentially the core elements of the ASP, including leadership and commitment from the hospital, participation and responsibility of health workers, interventions, education, monitoring and evaluation of effectiveness, and reporting and feedback. The core elements of the ASP require different levels of resources. Therefore, a facility does not necessarily need to apply all of these elements, but this depends on the capacity and priority goals of that facility at each stage. The following sections provide a detailed structure of a current best practice ASP and identify the key practical steps that are required to ensure implementation and sustainability in a medical facility.

1. *Key steps to establishing a healthcare facility ASP*

First, it is important to evaluate the past and present AMR situation in the local context within the hospital and the catchment community, as well as to assess the management measures already in place at the facility. This provides data for selecting appropriate elements of an ASP and prioritizing targets and resources for implementation. The next step is to select interventions and instigate them at the grassroots level. It is best to start with the ones that are easy to achieve and can be applied immediately, then plan and allocate resources to implement the others. Thereafter, continuously evaluate effectiveness and adjust interventions. In order to facilitate ongoing good practice, an important final measure is to provide education and training to stakeholders on antibiotic prescribing and use practices. This cycle of steps for implementing an ASP is shown in Figure 1.

**Figure 1:** **Order of steps in establishing a healthcare facility antimicrobial stewardship program.**

1. **Leadership Commitment and Accountability**
2. *Healthcare facility leadership*

Strong healthcare facility leadership is a crucial component of the success of an ASP. This leadership typically includes the Chief Medical Officer, Chief Nursing Officer, Director of Pharmacy, and other senior executives responsible for overseeing hospital operations. Their role can ensure that ASPs receive the necessary resources, staffing, and structural support to function effectively. This is essential because one of the major barriers to running a successful stewardship program is insufficient resources. First and foremost, support from the institution is important, especially in facilities without existing antibiotic stewardship interventions. Regular meetings between AMS leaders and senior executives help to assess ongoing needs, ensuring that the program aligns with broader hospital goals for patient safety and high-quality care. Leadership can also reinforce AMS initiatives by integrating stewardship activities into existing hospital programs, such as infection control and patient safety measures, making AMS a standing agenda item in committee meetings. Another key role of leadership is to ensure that all other relevant groups in the hospital are aware of stewardship efforts and, directly or indirectly, to promulgate clinical practice guidelines for antibiotic use in all hospitals under their governance.

Beyond organizational support, commitment to funding training and education for AMS teams and hospital staff, thereby ensuring continuous professional development in AMS, can help the ASP to flourish in the future. Additionally, leaders should facilitate participation in local, state, and national AMS improvement initiatives.

1. *Antimicrobial stewardship committee and AMS team*

The institutional AMS committee plays a hands-on role in making sure stewardship efforts are organized, effective, and actually making a difference to how antibiotics are used. Depending on the hospital’s structure, it can be its own stand-alone committee or be part of an existing one, such as for infection control or patient safety. The identification of a clear role for AMS and recognition of its ongoing priority, not just something that is discussed periodically, is a deciding factor in its effectiveness. The committee is responsible for setting goals, tracking antibiotic use, implementing interventions, and ensuring hospital policies align with national guidelines.

A strong AMS committee chair is key — this should be someone from the hospital leadership who can push for resources and keep AMS on the hospital’s agenda. The committee membership should include a mix of experts: infectious disease specialists, pharmacists, microbiologists, nurses, and information technology staff who can contribute different perspectives. Having regular meetings helps keep items on track, allowing the team to assess progress, troubleshoot issues, and adjust strategies as required. When properly supported, the AMS committee connects stewardship efforts across different hospital departments, making sure antibiotic use is not just a pharmacy or infectious disease issue, but part of overall patient safety and high-quality care. By giving authority to the committee and backing its needs, leadership ensures that AMS is not just a written policy that is not actioned — rather, it becomes part of daily hospital practice, leading to better prescribing habits, reduced antibiotic resistance, and improved patient outcomes.

An ‘AMS team’ is a group of healthcare professionals working together to improve how antibiotics are used in a healthcare facility. Their goal is to ensure that antibiotics are prescribed appropriately, prevent AMR, and ultimately improve patient outcomes. Depending on the size of the facility, the AMS team can be a full group of specialists or, in smaller settings, just one dedicated person overseeing the program. Ideally, the team includes a prescribing physician, a pharmacist, a nurse, a microbiologist and/or medical laboratory technician (if the facility has a diagnostic microbiology laboratory). If resources allow, having an infectious disease physician, a clinical pharmacologist, and a nurse with infection control expertise is also beneficial to strengthen the team’s impact. However, in smaller facilities where some roles are not available, AMS leadership may fall to a single physician, pharmacist, or nurse, with external support from a doctor or pharmacist when needed.

For the AMS team to function effectively, members need dedicated time for stewardship activities, and their responsibilities should be clearly outlined in their job descriptions and performance contracts. The team should have the authority and recognition, usually issued by the facility manager, needed to implement AMS interventions without barriers, especially in settings where hierarchical structures might limit the involvement of pharmacists and nurses. They need to work together regularly to monitor progress, discuss challenges, and adjust strategies based on antimicrobial use and resistance data. The AMS team must also collaborate closely with infection control, patient safety, and high-quality improvement efforts, making stewardship part of the broader hospital strategy rather than a separate initiative.

Several challenges are inherent to successful AMS and therefore require attention. Typically, lack of resources is a significant hurdle, with many facilities struggling to allocate sufficient staff and time for AMS activities. Leadership support is key to ensuring that the team has what it needs to be effective. Formal endorsement of pharmacists and nurses in stewardship roles is also crucial, especially in hospitals where the medical hierarchy can make it harder for non-physicians to take leadership roles in AMS. Training is another important factor — team members must have the right skills and knowledge to perform their roles effectively. Finally, because of the diversity of local context, available resources, and staff expertise, ASPs must be flexible and adaptable to create a program that works well for that given facility. With the right structure, support, and teamwork, an AMS team can significantly optimize antibiotic use and improve patient care.

1. Physicians

Physicians are at the core of AMS, which directly impacts how antibiotics are used in hospitals. This is because accurate diagnosis and responsible prescribing should reduce unnecessary antibiotic use and, therefore, decrease antibiotic resistance. One of the best ways to support this is through ongoing education, helping physicians to stay updated on local AMR patterns, global AMR threats, and the latest treatment guidelines. Seminars, case discussions, and regular guideline reviews, where prescribers from different departments — like intensive care unit (ICU) doctors and microbiologists — come together to review patient cases and discuss best practices, should improve AMS practice continuously. Encouraging multidisciplinary participation makes these infection control continuing professional development sessions more practical and clinically relevant.

Many hospitals have physicians leading ASPs, especially infectious disease specialists or experienced clinicians, although more pharmacists and nurses are stepping into leadership roles, with the understanding that they can always consult a physician when needed.

For ASPs to work well, all physicians need to be supportive and actively involved, not just a select few. Hospitalists, in particular, should be a major focus since they are among the greatest prescribers of antibiotics. Their involvement in quality improvement initiatives can make a big difference to how antibiotics are managed at the hospital level. The challenge is to ensure that AMS is not perceived as extra — and optional — workload but instead becomes an integral part of daily clinical practice.

1. Nurses

Nurses have the most direct and continuous interaction with patients. Their involvement goes beyond just antibiotic prescriptions — they focus on patient safety, timely medication administration, and infection prevention, which are all essential for effective AMS. Rather than treating AMS as a separate responsibility, engaging nurses through their existing roles in high-quality patient care makes their contribution more practical and meaningful. One of their key responsibilities is to ensure that antibiotics are administered on time without missed doses, and if therapeutic drug monitoring (TDM) is available, they help to track antibiotic levels in order to avoid under- or over-dosing. They also play a major role in microbiological sampling, making sure that cultures are collected properly before antibiotics are started and that laboratory results are communicated to prescribers.

Beyond medication management, nurses are in a unique position to monitor patient progress, assess the effectiveness of treatments, and identify potential side effects or signs that antibiotics are not working. They also help transition patients from intravenous (IV) to oral antibiotics when appropriate, reducing unnecessary IV therapy. Since nurses are routinely involved in the placement of catheters and other invasive devices, they can ensure proper handling in order to prevent hospital-acquired infections. Their role extends to data collection for audits and antimicrobial consumption (AMC) surveillance, and when supported by leadership, they can educate patients and their families, as well as colleagues, about responsible antibiotic use and infection prevention.

Nurses also help to determine whether or not certain tests, like urine cultures, are actually necessary rather than ordering them automatically. They can ensure that cultures are collected correctly before antibiotics are started, while prompting discussions about why a patient is on antibiotics, how long the treatment should last, and whether it is still needed.

Despite their significant role, nurses are often undervalued or overlooked entirely in AMS efforts. They need formal recognition and support from hospital leadership in order to fully engage in stewardship activities. It should be emphasized that instead of adding AMS as an extra task, it should be integrated into routine nursing care, making stewardship part of their day-to-day responsibilities.

1. Pharmacy and Therapeutics Committee

The Pharmacy and Therapeutics (P&T) Committee can help to develop guidelines, policies, and formularies in order to ensure antibiotics are used effectively, helping to reduce AMR and improve patient care. In many hospitals, a multidisciplinary AMS subcommittee is formed within the P&T Committee to focus specifically on AMS.

A major aspect of the P&T Committee’s work is reviewing and optimizing antibiotic use, from managing formularies and addressing medication stock shortages to conducting AMC audits and prescription reviews. The committee keeps track of how antibiotics are being used and updates policies as needed to make sure they are prescribed correctly. This facilitates integration of AMS practices as a routine part of patient care in the hospital workflows. One of the most effective ways to do this is by incorporating stewardship measures into electronic order sets and clinical pathways, making it easier for prescribers to follow evidence-based guidelines.

Strong pharmacist involvement is a key factor in the success of ASPs. Hospitals with infectious disease-trained pharmacists often achieve the best results. Still, even when such specialists are not available, general clinical pharmacists can step up — as long as they have proper training in AMS. Investing in formal stewardship training and certification programs for pharmacists, preferably as part of their continuing professional development, can significantly improve antibiotic use. Another important responsibility is handling medication shortages and stock-outs so that gaps in supply do not result in unnecessary changes in treatment or improper antibiotic use.

The P&T Committee acts as a bridge between physicians, microbiologists, and hospital administrators to ensure that stewardship strategies are both effective and practical. Regularly reviewing antibiotic use and resistance data helps to guide decisions and inform policy updates. With strong leadership, clear guidelines, and continuous training, the committee can integrate AMS into daily hospital operations, improving patient care and reducing antibiotic resistance.

1. Microbiology laboratory staff

Microbiology experts provide essential diagnostic support for identifying pathogens and guiding appropriate antibiotic use. The typical work of microbiologists and medical laboratory technicians is processing samples for diagnosis and antibiotic susceptibility testing for informing treatment decisions. One of their most important contributions is developing and regularly updating the hospital’s cumulative antibiogram, which tracks local AMR patterns and helps physicians to choose the right empiric antibiotics. Not all hospitals have an in-house microbiology laboratory, so smaller facilities often rely on external partnerships to access these services. Regardless of where testing is done, clear communication between microbiology staff and AMS teams is critical in order to ensure the effective use of laboratory data to underpin stewardship efforts.

A substantial part of microbiology’s role in AMS is diagnostic stewardship, ensuring that tests are ordered appropriately, performed properly, and results interpreted in a way that supports optimal antibiotic prescribing. Microbiology teams help ASPs by analyzing AMR trends, presenting laboratory data in a way that aligns with hospital guidelines, and leading discussions on new diagnostic tools and updated antibiotic breakpoints that could impact treatment decisions. Close collaboration between the microbiology laboratory and stewardship personnel ensures that test results are not just available but actually inform prescribing practices.

There are a few challenges that need attention. Not all hospitals have direct access to microbiology services, and delays in test results can sometimes lead to unnecessary broad-spectrum antibiotic use. This makes timely and efficient communication between laboratory teams and prescribers especially important. Laboratory findings also need to be presented in a way that is clear and useful for physicians, ensuring that resistance data directly influences hospital antibiotic policies. Regular discussions between microbiologists and AMS teams help to keep everyone informed and their actions aligned. Lastly, ongoing training for physicians on how to use microbiology results in their prescribing decisions can significantly improve AMS efforts.

1. Other human resources

Infection preventionists and hospital epidemiologists play a pivotal role in educating staff on AMR and tracking infection trends, particularly antibiotic resistance patterns of *C. difficile* and other difficult-to-treat pathogens. They also keep monthly reporting plans updated, adjusting user lists, and assisting with data uploads.

Quality improvement, patient safety, and regulatory staff contribute by advocating for resources and ensuring that AMS efforts are integrated into broader hospital quality initiatives, such as sepsis management. They also support the implementation and assessment of AMS interventions, making sure that the program is effective.

Information technology staff are required to embed stewardship protocols into clinical workflows, ensuring that prescribers can access order sets, facility-specific guidelines, and clinical decision support tools that prompt timely antibiotic reviews. They also manage and ensure accurate tracking of antibiotic use and resistance data.

1. **Antibiotic Stewardship Interventions**
2. *Barriers to AMS*

The obstacles to appropriate antimicrobial prescribing are numerous and complicated. While these vary depending on the specifics of each healthcare facility, conditions that cause inappropriate antibiotic use include:

* Physician knowledge deficits regarding the optimal use of antibiotics and fear that withholding antibiotics will lead to poor outcomes;
* Limited access to reliable clinical diagnostic or microbiological testing;
* Limited access to data, including antimicrobial prescribing trends, at a facility and of data regarding the prevalence of AMR in the community;
* Limited or lack of communication between healthcare providers, especially between physicians and expert teams (infectious disease physician, clinical microbiologist, clinical pharmacologist);
* Lack of resources and organizational support needed for AMS;
* Public access to antibiotics without prescription in the community or online.

AMS interventions are a means to overcome these barriers in order to promote optimal use of antimicrobials [5].

1. *Institution-specific guidelines for the management of common infections*

Institution-specific guidelines provide standardized, evidence-based recommendations for treating common infections while considering local AMR patterns, drug availability, and diagnostic capabilities. This ensures consistency in antibiotic prescribing, minimizes unnecessary use of broad-spectrum antibiotics, and improves overall patient outcomes. These guidelines are typically adapted from national or international protocols, such as from the Infectious Diseases Society of America (IDSA), but are tailored to fit institutional needs and real-world prescribing practices. Common infections targeted by these guidelines include respiratory tract infections, urinary tract infections (UTIs), and skin and soft tissue infections (SSTIs), as well as surgical site infection prophylaxis.

Institution-specific guidelines reduce variation in prescribing practices, ensuring that physicians across different hospital departments follow a standardized approach to diagnosis, empiric treatment, and therapy adjustments. They also support AMS monitoring efforts by creating benchmarks for appropriate antibiotic use, which can be tracked by prospective audit and feedback (PAF) programs. Additionally, these guidelines provide a structured framework for physician education, reinforcing best practices and promoting adherence to AMS principles.

In order to develop practical, evidence-based guidelines that are aligned with local treatment realities, collaboration between AMS teams, infectious disease specialists, pharmacists, and frontline physicians is essential. The guidelines should address diagnostic criteria, initial empirical therapy, de-escalation strategies, IV-to-oral switch protocols, and optimal treatment durations. Successful implementation depends on making these guidelines easily accessible — whether through electronic health records (EHRs), printed pocket cards, decision-support tools, or embedded order sets in prescribing workflows. Hospitals should also provide regular education and training sessions to increase physician awareness and compliance.

With a view to maintaining their relevance, institution-specific guidelines should be regularly reviewed and updated based on emerging AMR patterns, new clinical evidence, and formulary changes. Leadership support is crucial to ensuring that physicians actively participate in both guideline development and adherence. In settings where AMS resources are limited, targeting high-impact infections — such as those frequently associated with inappropriate therapy, excessive antibiotic duration, or suboptimal use of diagnostics — can be a good starting point. Selected ways in which to improve diagnostic accuracy by a hospital AMS team are shown in Table 2.

**Table 2: Improving accuracy of common infection diagnoses through enhanced in-hospital AMS.**

|  |  |  |
| --- | --- | --- |
| **Infection type** | **Inappropriate diagnosis** | **Improving diagnostic accuracy** |
| Urinary tract infection (UTI) | A positive urine culture often leads to a UTI diagnosis, even in the absence of specific signs or symptoms of sepsis. | UTI corresponds to the aggression of a tissue of the urinary tract by one or more microorganisms, associated with an inflammatory response and clinical signs. It must be differentiated from colonization, which corresponds to the presence of one or more microorganisms in the urinary tract without clinical manifestations.  Signs and symptoms consistent with UTI include urgency, frequency, dysuria, suprapubic pain, flank pain, pelvic discomfort, and acute hematuria. Non-specific signs and symptoms such as delirium, nausea and vomiting should be interpreted with caution as, by themselves, they have a low specificity for UTI.  Implement criteria for ordering urine cultures to ensure that positive cultures are more likely to represent infection than bladder colonization.  • Order a urine culture only if the patient has clinical signs;  • For patients with urinary catheters, avoid obtaining urine cultures based solely on cloudy appearance or foul smell in the absence of signs and symptoms of UTI.  Combine bacterial culture and urine cytology results to interpret urine culture results. The number of leukocyturia ≥ 10,000/mL is an indicator of inflammatory processes in the urinary tract. No clinical signs and leukocyturia ≤ 10,000/mL indicate simple bacterial colonization. Reminder to check for patient comorbidities; for example, those with hematological diseases or immunodeficiencies may have a generalized leukopenia. Leukocyturia criterion is non-contributory in the case of a patient with an endo-urinary device. |
| Pneumonia | Pneumonia due to non bacterial agents  Inappropriate diagnosis of pneumonia for other diseases, e.g., pulmonary cancer or exacerbation of congestive heart failure  Misdiagnosis of atypical pneumonia, caused by, e.g., *Legionella spp.* with pneumonia due to other agents | The use of viral diagnostics and/or procalcitonin may help to identify pneumonia caused by a virus or bacterium.  Inappropriate diagnosis of community-acquired pneumonia (CAP) defined as any antibiotic treatment of CAP in a patient with fewer than 2 signs or symptoms of pneumonia or who lacks radiographic findings consistent with pneumonia. Signs and symptoms of pneumonia include cough, sputum production, dyspnea or tachypnea (respiratory rate > 20 breaths/minute), hypoxemia (oxygen saturation < 90% or partial pressure of arterial oxygen < 60 mm Hg), fever (temperature > 38 ºC) or hypothermia (< 36 ºC), examination consistent with pneumonia (i.e., rales, crackles, dullness on percussion, bronchial breath sounds, or egophony), or leukocyte count < 4,000/μL; > 10,000/μL; or > 15% bands. For cases of hospital-acquired pneumonia, quantitative culture of respiratory specimens enhances the ability to determine if bacteria are normal flora or pathogens. For example, 10^7 is considered the threshold for pathogen identification in sputum, 10^5 in bronchoalveolar lavage. Ensure specimen quality (by leukocyte count and epithelial cell count) and discuss between physician and microbiologist to help determine whether or not antibiotic treatment is warranted for the isolated bacteria.  While Legionnaires' disease is clinically or radiographically indistinguishable from pneumonia caused by other pathogens, the first-line treatment for healthcare-associated or CAP does not always include *Legionella*-directed antibiotics. Beta-lactam antibiotics are inactive against *Legionella*; antibiotics active against this bacterium include macrolides, quinolones, and rifampicin. Appropriate testing must be performed to make the correct diagnosis in cases with indications. Testing includes for urinary antigen, polymerase chain reaction DNA amplification, and culture of lower respiratory tract secretions, sputum, and bronchoalveolar lavage using specific media. Discussion between physician and microbiologist for cases that require testing to provide timely and accurate treatment for patients: outpatient antibiotic failure for CAP; severe pneumonia; patients with known risk-factors (gender, age, immunocompromising condition, pulmonary edema). |
| Skin and soft tissue infections (SSTIs) | Uncomplicated infections can receive antibiotics with overly broad spectra | Develop diagnostic criteria to distinguish purulent and non-purulent infections and severity of illness (i.e., mild, moderate or severe) so that SSTIs can be managed appropriately according to guidelines. For example, in mild SSTIs microbiology tests are not needed and tissue swab cultures are to be avoided, especially in cases of intact skin with the risk of contamination and overtreatment. The microbiologist can check the validity of the specimen and provide feedback to the physician if necessary. Cloxacillin and cephalexin have a narrower spectrum of antibacterial activity compared to amoxicillin + clavulanic acid, with good efficacy. Use of methicillin-resistant *Staphylococcus aureus*-specific therapy may not be required in uncomplicated non-purulent cellulitis. |

Hospitals prescribe more than half of their antibiotics for a small set of infections where ASPs can have the biggest impact. These infections — CAP, UTIs, SSTIs, sepsis, *Staphylococcus aureus* bloodstream infections, *C. difficile* infections (CDIs), and culture-proven invasive infections — are common, but often mismanaged, leading to unnecessary antibiotic use, longer durations than needed, and an increased risk of resistance and adverse effects. AMS teams can improve patient care by enhancing diagnostic accuracy, ensuring therapy is tailored to culture results, optimizing treatment duration, and eliminating unnecessary broad-spectrum antibiotics.

* Community-acquired pneumonia (CAP)

A major issue with CAP is that many patients are treated for pneumonia when they do not actually have a bacterial infection, leading to unnecessary antibiotic use. AMS interventions focus on confirming the pneumonia diagnosis, especially after therapy has been started, to rule out non-infectious conditions like pulmonary edema, aspiration, or viral infections. Physicians should avoid empiric methicillin-resistant *S. aureus* (MRSA) treatment and antipseudomonal beta-lactams unless there are clear risk factors for resistant pathogens, as overuse of these broad-spectrum agents can increase resistance and lead to unnecessary side effects. Procalcitonin levels and MRSA nasal swab testing can help to determine whether empiric MRSA or broad-spectrum coverage is needed — or if it can be safely discontinued.

Duration of therapy is another critical intervention, as many CAP patients receive antibiotics for longer than guidelines recommend. Most uncomplicated CAP cases can be treated with just five days of antibiotics, provided that the patient shows clinical improvement. Reducing excess antibiotic use after hospital discharge is also a key target, as many patients continue unnecessary therapy after leaving the hospital. AMS teams should implement discharge stewardship strategies to ensure post-hospital antibiotic courses are appropriate and not excessively prolonged.

* Urinary tract infections (UTIs)

One of the most frequent problems in UTI management is the overuse of antibiotics for asymptomatic bacteriuria, which does not require treatment in most cases. In order to address this, ASPs should implement criteria for ordering urine cultures, ensuring that positive results are only acted upon when the patient has true symptoms of infection — such as urgency, frequency, dysuria, flank pain, or acute hematuria. For catheterized patients, AMS teams should discourage urine cultures based on cloudy or foul-smelling urine alone, as these findings are not reliable indicators of infection. Non-specific symptoms like delirium, nausea, and vomiting should also be interpreted cautiously, as they have low specificity for diagnosing UTIs.

For true UTIs, AMS efforts should focus on ensuring appropriate therapy selection based on local AMR patterns and using the shortest effective antibiotic duration. Overly long courses of antibiotics increase the risk of CDIs and resistance without improving outcomes. AMS teams should also establish clear criteria to distinguish between asymptomatic and symptomatic bacteriuria, limiting treatment of asymptomatic cases to only pregnant women or patients undergoing invasive urological procedures.

* Skin and soft tissue infections (SSTIs)

Misuse of broad-spectrum antibiotics, particularly MRSA coverage, is a major problem in SSTI management. ASPs should focus on helping physicians to distinguish between purulent and non-purulent infections, as well as assessing severity (mild, moderate, or severe) to guide appropriate therapy. For mild to moderate cases, MRSA coverage is often unnecessary, and narrower-spectrum beta-lactams like cephalexin or penicillin are sufficient.

Many patients with SSTIs also receive antibiotics for longer than necessary. Most uncomplicated bacterial cellulitis cases can be treated in just five days, as longer durations do not improve outcomes but increase resistance risk. Additionally, antipseudomonal beta-lactams and anaerobic agents should be avoided unless clearly needed, as routine broad-spectrum coverage for SSTIs is unnecessary and promotes AMR.

* Sepsis

Sepsis requires rapid antibiotic administration, but once a patient is stabilized, AMS teams should step in to reassess therapy. The key AMS interventions for sepsis include developing local antibiotic recommendations based on microbiology data, ensuring early, appropriate empiric therapy, and then reviewing antibiotics regularly to de-escalate therapy when possible. Empiric broad-spectrum therapy should not be continued unnecessarily, and AMS teams should work with ICU and emergency teams to ensure protocols allow for appropriate antibiotic adjustments once culture results are available.

* *Staphylococcus aureus* bloodstream infections

A critical AMS intervention for *S. aureus* infections is ensuring that patients with methicillin-susceptible *S. aureus* infections are switched from vancomycin to beta-lactams, which are more effective and associated with better outcomes. Additionally, MRSA therapy should be stopped if the infection is not actually due to MRSA, avoiding unnecessary use of vancomycin or linezolid. Studies show that AMS-led treatment protocols and infectious disease consultations improve outcomes in patients with *S. aureus* bloodstream infections, thereby reducing the rates of treatment failure and complications.

* *Clostridioides difficile* infections (CDIs)

Inappropriate antibiotic use is one of the biggest drivers of CDIs. AMS teams should prioritize reviewing and stopping unnecessary antibiotic treatment of patients diagnosed with a CDI, as continuing antibiotics increases recurrence risk and worsens clinical outcomes. Another important AMS intervention is to ensure that patients receive guideline-recommended therapy, particularly with oral vancomycin or fidaxomicin, rather than older, less effective treatments like metronidazole.

* Culture-proven invasive infections (e.g., bloodstream infections, meningitis, osteomyelitis)

Invasive infections provide a key opportunity for AMS intervention, as they are easily identified through microbiology results and require careful antibiotic selection. AMS teams should use PAF to ensure that therapy is promptly narrowed, broadened, or discontinued based on culture results. Delays in modifying treatment can lead to worse patient outcomes, prolonged hospital stays, and higher AMR rates.

1. *Cumulative antibiograms*

A cumulative antibiogram is a report, typically provided in-house at weekly or monthly intervals, and published annually, that compiles local antimicrobial susceptibility data. This shows which bacterial isolates currently remain sensitive to certain antibiotics in the healthcare facility or community. It is a key tool in AMS because it helps to guide empiric antibiotic choices, ensuring that initial treatments are based on local AMR patterns rather than guesswork. Over time, antibiograms also help to track the emergence of resistance trends, such as increasing MRSA cases, and they play a major role in shaping hospital-specific prescribing guidelines. In many settings, frontline physicians are trained to use antibiograms to make better empiric antibiotic decisions.

In order for antibiograms to be useful, they must be developed according to established guidelines. The Clinical and Laboratory Standards Institute recommends that to ensure accuracy only microorganisms with at least 30 non-replicative isolates be included [9]. Enhanced cumulative antibiograms, as suggested by US guidelines, can be even more informative, especially when stratified by hospital unit (e.g., ICU, Emergency Room) or specific patient populations (e.g., pediatric, immunocompromised). However, producing these detailed antibiograms can be resource-intensive and requires a well-functioning microbiology laboratory that follows standardized testing protocols to maintain data consistency.

There are several challenges that need attention. Building and maintaining an antibiogram takes time and expertise, so therefore requires coordination between microbiology staff, IT support, and leadership backing. Since the process involves large-scale data aggregation, hospitals also need strong IT infrastructure to ensure accurate reporting. Another key factor is physician education — an antibiogram is only useful if prescribers know how to interpret and apply the data in their decision-making. Hospitals should also decide how to distribute antibiograms effectively, whether through electronic decision-support tools, paper-based reports, or embedded systems at the point of care. When properly developed and used, cumulative antibiograms improve antibiotic selection, track AMR patterns, and strengthen ASPs, making them an essential tool to use in any hospital with a reliable microbiology laboratory.

1. *Prior authorization of restricted antimicrobials*

Prior authorization is a key AMS intervention that requires physicians to attain approval before prescribing restricted antimicrobials. This process is usually handled by AMS team members, pharmacists, or infectious disease physicians, including trainees. The goal is to closely monitor and control the use of targeted antibiotics in order to prevent resistance and optimize empiric antibiotic use, manage drug shortages, reduce dosing errors, and lower the risk of antibiotic-associated infections, such as *C. difficile*. It should be noted that this approach can sometimes lead to prescriber frustration or delays in drug administration, especially in urgent cases; thus, there should be regulations to minimize this.

The prior authorization process follows a structured workflow: a physician orders a restricted antimicrobial, seeks approval from an AMS approver (such as an infectious disease specialist or pharmacist), and, based on the evaluation, either receives approval to proceed or is given an alternative recommendation. This workflow allows direct interaction between prescribers and AMS teams and creates opportunities for education, reinforcing best prescribing practices and also avoiding delays in prescribing.

For this system to work effectively, real-time access to AMS personnel is crucial, especially in hospital settings in which delays could compromise patient outcomes. In urgent cases such as septic shock, some hospitals allow initial dosing while approval is pending in order to avoid treatment delays. When there is a disagreement between an AMS team and a prescriber over antibiotic use, institutional support is necessary. Since not all hospitals have the resources for 24/7 prior authorization, some choose to limit approvals to select high-risk antibiotics or apply it only during business hours, allowing initial doses to be given without approval after hours.

Prior authorization is most effective when combined with other AMS strategies, such as formulary restrictions, PAF, and the WHO Access, Watch, Reserve (AWaRe) classification system to determine which antibiotics require restriction (Table 3) [10].

**Table 3: Levels and examples of restricted antimicrobials.**

|  |  |  |  |
| --- | --- | --- | --- |
| **Level of Restriction** | **Description** | **Examples** | **Reasons for Restriction** |
| Red | Highly restricted antimicrobials. Their use is limited due to factors such as broad-spectrum activity, being last-resort options, high toxicity, and/or cost. Prescription typically requires approval from an expert, such as an infectious disease physician or microbiologist, before administration. | Colistin, Linezolid | Broad-spectrum activity: to preserve effectiveness and prevent resistance development.  Last-resort options: reserved for cases where other treatments have failed.  High toxicity: to ensure patient safety through expert oversight.  High cost: to manage healthcare resources effectively. |
| Amber | Antimicrobials with a lower level of restriction. They can be prescribed without prior approval for specific indications but require authorization for other uses or extended therapy durations. These drugs may have associated toxicity risks or potential to induce resistance but are recommended as first- or second-line agents in hospital guidelines. | Vancomycin, Ceftriaxone, Piperacillin-Tazobactam | Potential toxicity: monitoring to prevent adverse effects.  Risk of resistance: controlled use to minimize the development of resistant microorganisms.  Guideline recommendations: ensuring adherence to hospital protocols for specific conditions. |
| Green | Antimicrobials with no restrictions on their use. They can be prescribed without prior approval and are generally narrow-spectrum agents with low potential to induce resistance. These are commonly listed as first-line treatments in hospital guidelines. | Amoxicillin, Cefazolin | Narrow-spectrum activity: targets specific pathogens, reducing the impact on normal flora.  Low resistance potential: less likely to contribute to AMR.  First-line recommendations: aligns with standard treatment protocols for common infections. |

1. *De-labeling of spurious antibiotic allergies*

Many patients are labeled as having antibiotic allergies, but in reality, a significant number of these are either inaccurate or no longer relevant. Incorrect allergy labels, especially for beta-lactams like penicillin, often lead to unnecessary use of broad-spectrum or second-line antibiotics, increasing treatment costs, hospital stays, and the risk of AMR. De-labeling involves reassessing these reported allergies through detailed history-taking, skin testing, and oral challenge tests to determine whether the allergy is real or if the patient can safely take the antibiotic.

This process allows physicians to improve their ability to document accurate allergy histories and use first-line antibiotics whenever possible, reducing the need for IV therapy or broad-spectrum alternatives. Patients should benefit from more effective treatments, fewer side effects, and shorter hospital stays. It also leads to significant cost savings by reducing the use of expensive alternative antibiotics.

The de-labeling process typically starts with a comprehensive allergy history, whereby physicians determine if a past reaction was a true allergic response or simply a side effect (e.g., nausea or headaches). For beta-lactam allergies, skin prick and intradermal testing can assess immunoglobulin E-mediated reactions. If these tests are negative, an oral antibiotic challenge is performed under medical supervision to confirm tolerance. If the patient does not react, the incorrect allergy label is removed from their medical record, ensuring that future treatments are not unnecessarily limited.

Successfully implementing an antibiotic allergy de-labeling program requires trained healthcare providers (such as allergists or pharmacists with AMS expertise), access to testing reagents, and a safe environment to manage rare severe reactions. Institutional support is key, as hospitals need to allocate resources, train staff, and educate both physicians and patients on the benefits of de-labeling. Patient acceptance is also critical — many need reassurance and clear communication about why this process is safe and beneficial.

This intervention is best suited for moderate to large hospitals, academic medical centers, or outpatient clinics with access to allergy specialists. It is especially useful for preoperative evaluations to ensure patients receive the correct surgical prophylaxis antibiotics, or for inpatients needing long-term therapy for conditions like endocarditis or osteomyelitis. Facilities with EHRs can also use them to identify and track patients with outdated allergy labels more efficiently.

1. *Prospective audit and feedback (PAF)*

PAF is a core AMS intervention that involves real-time review of ongoing antibiotic therapy, ensuring that antimicrobials are used appropriately throughout a patient’s treatment. There is a key difference between other pre-prescription authorizations, where approval is required before an antibiotic is given, and PAF, which allows AMS teams to assess prescriptions after they have been started, providing direct recommendations to prescribers when adjustments are needed. This approach helps to optimize therapy, prevent overuse of broad-spectrum antibiotics, and improve patient outcomes. PAF is designed to be persuasive rather than restrictive, meaning that the AMS team provides rationale-backed recommendations while still respecting prescriber autonomy. By engaging with frontline physicians regularly, PAF strengthens AMS visibility in hospitals, builds trust with prescribers, and improves long-term prescribing behaviors.

Identifying patients on selected antimicrobials, often through EHRs, automated surveillance systems, or manual tracking methods like color-coded chart stickers, is the first step. Once flagged, an AMS pharmacist or infectious disease specialist reviews the patient’s medical records, laboratory results, and clinical progress to assess whether the current antibiotic regimen is appropriate. If an adjustment is needed, the AMS team reaches out to the prescriber — either through face-to-face discussions (often called "handshake stewardship"), phone calls, or electronic messages — to provide recommendations. These discussions focus on improving therapy selection, adjusting dosages, shortening treatment durations, or switching from IV to oral antibiotics when appropriate. Importantly, follow-ups help to track whether recommendations were implemented and to evaluate the impact of intervention on patient care.

There are obvious benefits of PAF such as reducing unnecessary antibiotic use, lowering healthcare costs, preventing adverse effects like CDI, and minimizing dosing errors. In fact, studies have shown that PAF can lead to greater reductions in antibiotic consumption compared to pre-prescription authorization because it actively engages prescribers and encourages long-term behavior change. Its successful implementation in large academic hospitals, ICUs, children’s hospitals, small community hospitals, and even skilled nursing facilities demonstrates its versatility [11].

However, for PAF to be effective, certain challenges must be addressed. Staffing is a key factor, as successful implementation requires AMS team members with expertise in infectious diseases or antimicrobial use. In the USA, guidelines recommend that an infectious disease physician and a clinical pharmacist trained in AMS lead these efforts. In resource-limited settings, where such specialists may not be available, AMS teams can focus on common infections (e.g., pneumonia, UTIs, SSTIs) and compare treatment courses to local guidelines. Strong leadership support is also essential to increase prescriber acceptance and integrate AMS recommendations into routine hospital workflows. One point to note is that effective communication strategies are necessary — AMS teams must deliver feedback in a respectful, collaborative manner, as resistance from prescribers can undermine the ASP’s success.

Given its flexibility, PAF can be tailored to fit different healthcare settings. In hospitals with limited resources, AMS teams may target only specific high-risk antibiotics or perform audits a few times per week. It is particularly effective in facilities with microbiology capabilities, in which instance therapy can be adjusted based on culture and sensitivity results. Additionally, institutions that are developing AMS guidelines can use PAF as a way to reinforce adherence to hospital-specific treatment protocols.

1. *Self-directed antibiotic reassessments (antibiotics timeouts)*

Antibiotic timeouts are a simple but effective intervention that prompts prescribing physicians to reassess ongoing antibiotic therapy, typically 48–72 hours after initiation. This involves reevaluating whether the chosen antibiotic is still necessary, whether the spectrum should be narrowed, or if adjustments in dose or duration are needed, since antibiotics are often started empirically before culture results are available. However, in many cases, broad-spectrum agents are used continuously because physicians do not routinely review antibiotic prescriptions once they are started, while a more targeted therapy could be used. Antibiotic timeouts help to prevent this inertia by encouraging deliberate reassessment, thereby ensuring that therapy remains appropriate throughout hospitalization.

The prescribing provider takes responsibility for reviewing the antibiotic and making necessary modifications. This means that antibiotic timeouts are physician-driven, preserving their decision-making autonomy while still reinforcing good stewardship practices. Pharmacists or nurses can sometimes incorporate collaborative reviews into the timeout process to help ensure treatment decisions align with best practices and institutional guidelines.

When conducting an antibiotic timeout, physicians are encouraged to ask four key questions [8]:

* Does the patient still require antibiotics, or was the initial diagnosis incorrect?
* Have the necessary cultures and diagnostic tests been performed and reviewed?
* Can therapy be stopped, de-escalated to a narrower-spectrum antibiotic, or switched from IV to oral?
* How long should antibiotic therapy continue, considering both inpatient and post-discharge treatment?

By structuring reassessments around these questions, antibiotic timeouts help to reduce unnecessary antibiotic use, lower AMR risks, and improve patient outcomes. Some hospitals implement timeouts using EHR prompts that automatically remind providers to reassess therapy after a set number of days. Others use manual checklists, structured discussions in ward rounds, or pharmacist-led interventions to ensure reviews take place consistently. Institutions can prioritize timeouts for high-risk antibiotics, particularly those classified under the "Watch" and "Reserve" categories in the AWaRe system, where inappropriate use has the greatest potential to drive AMR.

While antibiotic timeouts are a valuable supplement to ASPs, they should not be seen as a replacement for PAF or other stewardship interventions. The optimal timing and frequency of antibiotic timeouts are still debated, but many experts recommend daily reassessments until a definitive treatment plan is established. Leadership support and physician buy-in are essential for ensuring timeouts become part of routine practice, as providers need both education and clear workflows in order to integrate these reviews into their daily decision-making. One common difficulty is that of receiving microbiology data and rapid diagnostics in sufficient time — without timely access to culture results, physicians cannot make informed de-escalation decisions.

Antibiotic timeouts are most effective for inpatient settings where empiric therapy is commonly initiated, and they work best when paired with other AMS strategies, such as PAF and institution-specific treatment guidelines. Whether done through self-guided reviews, team-based assessments, or EMR alerts, structured antibiotic timeouts help to reinforce good prescribing habits, reduce broad-spectrum antibiotic overuse, and ensure that patients receive the most appropriate therapy for their condition.

1. *Dose optimization*

Antibiotic optimization requires careful consideration of individual patient factors that influence the appropriate dose, interval, and route of administration. Under-dosing can lead to ineffective treatment and contribute to AMR, while excessive dosing increases the risk of side effects. Dose optimization improves patient outcomes while minimizing drug-related harm and AMR development. Factors such as age, weight, and renal function must be assessed alongside infection-specific considerations, such as severity, location, and the pathogen involved. While this process is typically part of the initial prescription, it remains important throughout treatment, especially for patients whose clinical status changes significantly — such as those transferred to the ICU or started on hemodialysis.

This measure is especially necessary for certain vulnerable groups of patients including those with severe kidney dysfunction requiring dialysis, those with liver failure, or who are otherwise in a critical condition. Each antibiotic needs to be dose-optimized for different reasons and circumstances. For example, extended-infusion administration of beta-lactams in critically ill patients is necessary due to their time-dependent killing mechanism. Caution should be taken when using vancomycin and aminoglycosides due to their renal toxicity. Daptomycin should not be given to patients with pneumonia because it is inactivated by surfactant. Table 4 shows examples of situations in which dose optimization is required according to IDSA guidelines [12-14].

**Table 4: Reasons for dose optimization of commonly prescribed antibiotics.**

|  |  |  |
| --- | --- | --- |
| **Antibiotic** | **Reason for Optimization** | **Optimization Strategy** |
| Ampicillin-sulbactam | High-dose regimens are necessary to treat carbapenem-resistant *Acinetobacter baumannii* (CRAB) infections effectively. | Administer a 27 g total daily dose (18 g ampicillin, 9 g sulbactam) as extended or continuous infusions, e.g., 9 g IV every 8 hours infused over 4 hours. |
| Non-carbapenem beta-lactam agents (i.e., piperacillin-tazobactam, ceftazidime, cefepime) | For *Pseudomonas aeruginosa* isolates not susceptible to carbapenems but susceptible to traditional beta-lactams, optimized dosing is crucial. | Utilize high-dose extended-infusion therapy to maintain drug concentrations above the minimum inhibitory concentration (MIC) for an extended period. |
| Fluoroquinolones | Risk of resistance development and severe side effects, including tendinitis, tendon rupture, and QT interval prolongation. | Prescribe only when necessary, adjust dosing based on renal function, and monitor for adverse effects. Ensure appropriate duration of therapy to minimize resistance development. |
| Polymyxins | Due to significant nephrotoxicity and neurotoxicity risks, precise dosing is essential. | Administer a loading dose of 2.0–2.5 mg/kg based on total body weight, followed by a maintenance dose of 1.25–1.5 mg/kg every 12 hours, infused over 1 hour. |
| Vancomycin | Narrow therapeutic window; risk of nephrotoxicity and ototoxicity if not properly dosed. | Implement ‘area under the curve’-guided dosing and monitoring to adjust dosing to the MIC ratio of 400–600 mg•h/L. Utilize therapeutic drug monitoring to ensure efficacy and minimize toxicity. |

Clinical pharmacologists, who excel in combining clinical, microbiological, and pharmacological insights, play an invaluable role in giving dosing advice. It should be noted, however, that this can present a drawback, as a certain understanding of pharmacokinetics/pharmacodynamics principles is required. Dose optimization is not always feasible for all patient populations, so it may be appropriate to start with high-risk patient groups such as those in the ICU.

1. *Duration optimization*

Selecting the right duration of antimicrobial therapy plays a crucial role in effective infection management and is a core component of successful AMS. Recent evidence supports shorter treatment courses for several common infections, including intra-abdominal infections and pneumonia, thus challenging traditional, longer-duration approaches. Ongoing research aims to refine duration recommendations for other clinical conditions.

Various stewardship strategies help to optimize therapy duration, such as guideline-based prescribing and audit-and-feedback mechanisms. In determining the appropriate length of treatment multiple factors need to be considered, including the type of infection, microbiologic findings, the patient’s clinical response, and whether treatment is given in an inpatient or outpatient setting [15]. While an initial estimate of duration is necessary at the start of treatment, ongoing assessment of the patient’s progress ultimately determines the final course length.

**Table 5: Factors involved in considerations of duration optimization.**

|  |  |  |  |
| --- | --- | --- | --- |
| **Syndrome/Infection** | **Antibiotics** | **Duration Strategy** | **Notes** |
| Community-acquired pneumonia (CAP) | Various beta-lactams, macrolides, fluoroquinolones | Minimum 5 days; consider IV-to-oral switch | Ensure the patient is afebrile for 48-72 hours and stable before discontinuation |
| Hospital-acquired pneumonia/ventilator-associated pneumonia | Broad-spectrum beta-lactams (e.g., piperacillin-tazobactam, carbapenems) | 7 days | Reduce risk of resistance and toxicity |
| Acute uncomplicated cystitis | Nitrofurantoin, trimethoprim-sulfamethoxazole, fosfomycin | 3-5 days | Prevent unnecessary exposure and resistance |
| Complicated pyelonephritis | Fluoroquinolones, beta-lactams | 5-7 days (up to 14 days if response is slow) | Tailor to the patient based on clinical response |
| Cellulitis/abscesses | Beta-lactams, clindamycin | 5 days, extend if there is no improvement | Avoid overtreatment; for abscesses, drainage is preferred |
| Osteomyelitis (*S. aureus*) | Vancomycin, beta-lactams | 6 weeks, longer if chronic infection | Reduce excessive treatment while ensuring bacterial clearance |
| Septic arthritis (non-hardware) | Ceftriaxone, vancomycin | 3 weeks, consider oral step-down | Prevent extended therapy while ensuring resolution |
| Diabetic foot infections (soft tissue only) | Beta-lactams, vancomycin, fluoroquinolones | 1-2 weeks, assess need for de-escalation | Avoid prolonged therapy if the infection resolves |

Under-treating an infection by shortening therapy risks incomplete resolution, while unnecessarily prolonged treatment increases the likelihood of AMR development and adverse effects. Duration optimization is a common AMS strategy, reinforcing the principle that effective antimicrobial use involves prescribing “the right drug at the right dose for the right duration”. Clinical considerations such as patient age, renal function, infection site and severity, pathogen identity, and drug administration method all play a role in tailoring the appropriate treatment length.

Several targeted strategies can be used to integrate therapy duration into clinical practice. Incorporating duration guidelines into clinical protocols is often done to ensure that this is a standard part of treatment decision-making. However, this approach is rather mechanical and difficult to put into practice. Audit and feedback interventions should specifically address therapy duration, helping to reinforce appropriate prescribing habits. Embedding a designated field for expected treatment duration in prescription order forms — whether paper or electronic — ensures that duration is considered at the time of prescribing.

Discussion of optimal duration can be included in clinical training, providing case-based evidence so that everyday prescribers understand its importance and know how to consider it. Additionally, when available, procalcitonin testing can support informed decision-making regarding the discontinuation of antibacterial therapy, helping to minimize unnecessary antibiotic use.

1. **Monitoring and Evaluation of AMS Interventions**
2. *Introduction to indicators in ASPs*

The goal of attaining clear, measurable indicators for when AMS interventions are needed provides the rationale to assess an ASP’s impact and to continuously introduce improvements. With this objective in mind, AMS teams seek to identify prescribing issues, evaluate the success of interventions, and allocate resources efficiently. While qualitative improvements can be made without data, structured monitoring ensures long-term sustainability and accountability. Since no single metric can fully capture antibiotic use and its effects, ASPs track multiple types of indicator in order to gain a comprehensive overview. These generally fall into three categories: structural indicators, which assess ASP infrastructure, leadership commitment, and policies; process indicators, which measure how well AMS activities are being implemented; and outcome indicators, which evaluate the direct impact of AMS efforts on antibiotic consumption, AMR patterns, and patient outcomes. Choosing the right indicators, tailored to an institution’s specific needs and capabilities, helps AMS teams to continuously refine their strategies and improve patient care.

Structural measures evaluate the capacity, systems, and processes within a healthcare facility or organization to support effective AMS implementation. At both national and facility levels, core elements serve as foundational structures that enable the successful development and execution of ASPs. These elements serve to ensure that facilities have the necessary leadership, policies, and resources in place to drive stewardship efforts forward.

Process indicators focus on how AMS interventions are implemented and integrated into daily clinical workflows. These measures track prescriber behaviors, adherence to antibiotic guidelines, and the execution of AMS strategies such as PAF, antibiotic timeouts, and formulary restrictions. For example, AMS teams may monitor how frequently prescribers reassess antibiotic therapy, how often guideline-recommended antibiotics are used, or if physicians document clear justifications for their prescriptions. Process indicators are critical because they provide real-time feedback on AMS activities, showing whether stewardship interventions are being followed consistently or if adjustments are needed. Since successful ASPs rely on strong physician engagement, tracking process measures ensures that stewardship efforts are influencing prescribing decisions in a meaningful way.

Outcome indicators assess the overall impact of AMS interventions on antimicrobial use, AMR trends, and patient health outcomes. One of the main goals of AMS is reducing unnecessary antibiotic use, especially broad-spectrum agents, without compromising patient safety. In order to measure this, ASPs track total AMC, defined daily dose (DDD), and the proportion of prescriptions that shift from broad-spectrum to narrower, targeted therapies. Yet, the role of AMS is not just about reducing antibiotic use — it is also about improving patient outcomes. That is why AMS teams also monitor AMR rates, CDI rates, hospital readmission rates, and length of stay to ensure that efforts to optimize prescribing do not lead to unintended harm. By tracking both antibiotic consumption and patient safety outcomes, ASPs can demonstrate their effectiveness and make a strong case for continued support and investment.

1. *Process measures in AMS*

Process indicators are essential for measuring how well AMS interventions are being implemented and whether, and to what extent, they are leading to meaningful improvements in antibiotic prescribing and use. These indicators act as proxy measures, enabling AMS teams to track if prescribing behaviors are moving in the right direction and where further education, policy adjustments, or targeted interventions may be necessary [5]. Since the goal of AMS is to optimize antibiotic use while maintaining patient safety, process indicators provide valuable insights into how frequently antibiotic use is reviewed, how well physicians adhere to treatment guidelines, and whether stewardship strategies are making an impact. By selecting indicators that align with specific AMS interventions, hospitals can ensure that their efforts are data-driven and focused on areas with the greatest potential for improvement.

ASPs use process indicators to assess key aspects of antibiotic prescribing and stewardship efforts. For example, to identify the frequency with which antibiotic prescribing is reassessed and whether adjustments are being made when needed, an AMS team can track medical chart reviews. Monitoring adherence to facility-specific treatment guidelines help to ensure that prescribers follow evidence-based recommendations for common infections. Moreover, analyzing the acceptance rate of PAF recommendations helps to identify areas where physicians may need additional support or education. Preauthorization interventions can also be evaluated by monitoring restricted antibiotic requests to ensure that necessary treatments are not being delayed while still maintaining appropriate oversight.

There are several priority process indicators. Monitoring how often antibiotic timeouts are performed ensures that physicians regularly reassess ongoing therapy and adjust it based on patient progress. Conducting medication use evaluations for specific antibiotics or infections can help to identify overuse, inappropriate combinations, or prolonged therapy durations. Another key measure is tracking IV-to-oral conversions, which highlights missed opportunities to switch patients from IV to oral therapy, thus reducing hospital stays and costs. Furthermore, AMS teams should assess how often duplicate therapy occurs, such as prescribing two antibiotics with overlapping coverage, and ensure that patients discharged from the hospital are given the correct antibiotic at the right dose and duration.

**Table 6: Selected process indicators related to antibiotics use.**

|  |  |
| --- | --- |
| **Indicator** | **Formula** |
| Documented indication for antibiotic use | (number of patients with a written indication for antibiotic treatment) / (total number of patients treated with antibiotic(s)) |
| Stop/review date documentation | (number of patients with a written stop/review date for antibiotic treatment) / (total number of patients treated with antibiotic(s)) |
| Compliance with clinical treatment guidelines | (number of patients with an indication receiving empirical treatment with antibiotic(s) according to clinical guidelines) / (total number of patients with this indication) |
| Length of therapy by indication | (total number of days of antibiotic treatment for a specific indication) / (total number of patients treated with antibiotic(s) for that indication) |
| 48-hour review | (number of patients where a 48-hour review is performed) / (total number of patients treated with antibiotic(s) hospitalized > 48 hours) |
| De-escalation rate | (number of patients where a de-escalation from the initial therapy is performed) / (total number of indicated empirical treatments) |
| IV-to-oral switch | (number of regimens switched to oral route) / (total number of regimens that can be switched to oral route based on predefined criteria) |
| Compliance with surgical prophylaxis guidelines | (number of patients receiving surgical antibiotic prophylaxis according to guidelines) / (total number of surgical patients receiving antibiotic prophylaxis) |
| Surgical prophylaxis within the previous 60 minutes | (surgeries with prophylaxis administered within 60 minutes prior to surgery) / (total number of surgeries that require prophylaxis) |
| Surgical prophylaxis stopped within 24 hours after surgery | (surgeries with prophylaxis stopped within 24 hours after surgery) / (total number of surgeries that require prophylaxis) |

1. *Outcome measures in AMS*

A key goal of ASPs is to reduce overall AMC and decrease the use of broad-spectrum antibiotics without compromising patient safety. However, simply lowering antibiotic use is not sufficient — ASPs must also ensure that reductions do not lead to unintended negative outcomes, such as increased mortality, longer hospital stays, or higher rates of recurrence of infection. In order to measure the effectiveness and safety of AMS interventions, outcome indicators must be tracked. These indicators help to evaluate changes in antibiotic use, AMR patterns, infection rates, and financial impact, thereby providing a clear picture of how stewardship efforts influence both hospital operations and patient health.

1. Measuring antibiotic use and its impact

Accurately measuring antibiotic use is a fundamental aspect of an ASP, as it provides the necessary data to monitor prescribing trends, identify areas for improvement, and assess the impact of stewardship interventions. Different metrics are used to quantify antibiotic consumption, each with its own advantages and limitations. The two most commonly used standardized measures are DDD per 100(0) patient-days and days of therapy (DOT) per 1000 patient-days, both of which help AMS teams to track antimicrobial use over time and benchmark against institutional or national standards.

DDD per 100(0) patient-days is one of the most frequently used metrics because it relies on aggregated pharmacy data rather than individual patient-level records. It is calculated using the total DDD of an antibiotic agent dispensed, purchased, or consumed within a specific time period, divided by the total number of patient-days in that period, then multiplied by 100(0) to standardize the measure. This indicator is widely applicable as it does not require electronic prescribing systems or individual patient data. However, the accuracy of DDD measurements can vary depending on data sources — for example, pharmacy dispensing data may overestimate actual antibiotic administration compared to electronic prescribing records or nursing chart documentation. Also, different facilities may include different antibiotic classes in their calculations, making comparisons difficult. Alternatively, DDD can be calculated per admission, which provides a different perspective by considering total hospital admissions rather than patient-days. This enables adjustment for variations in length of stay. DDD per admission measures total antibiotic consumption per hospitalized patient, calculated as total DDD used divided by total hospital admissions. Unlike DDD per 100(0) patient-days, which adjusts for hospital stay duration, DDD per admission provides insight into antibiotic exposure per patient, regardless of length of stay. This metric is often used to compare antibiotic use across hospital units with different patient turnover rates, such as short-stay surgical units versus ICUs. However, it does not account for treatment duration or dose adjustments based on individual patient factors.

While DDD per 100(0) patient-days is widely used, DOT per 1000 patient-days is often considered a more clinically relevant measure as it captures the number of days that a patient actually receives an antibiotic, regardless of the dose. DOT is calculated by counting the total number of days of therapy for a specific antibiotic agent within a given period, divided by total patient-days, then multiplied by 1000 to standardize the result. Unlike DDD, which assumes an average standard dose per day, DOT accounts for dose variability and allows for a more accurate evaluation of treatment duration and redundant therapy. However, the major limitation of DOT is that it requires individual patient-level data (electronic prescribing records, nursing chart documentation, or administrative data from electronic drug administration systems). This makes it more resource-intensive compared to DDD, which can be derived from aggregated pharmacy purchasing or dispensing data.

Each of DDD and DOT has its place in AMS monitoring, and many programs use both metrics together to gain a more comprehensive understanding of antibiotic use patterns. While DDD is easier to calculate and useful for broad consumption trends, DOT is more precise in evaluating treatment duration and assessing inappropriate or prolonged antibiotic use. ASPs may categorize antibiotic consumption based on the AWaRe classification [10], or other relevant groupings, ensuring that monitoring efforts align with global and national AMS priorities.

1. Outcome measures for AMS effectiveness

Tracking outcome measures is essential in ASPs in order to ensure that efforts to reduce antibiotic use and AMR do not negatively impact patient safety. One of the most critical indicators is CDI rates, as inappropriate antibiotic use is a major driver of CDI cases. AMS teams should focus on reducing broad-spectrum antibiotic exposure, optimizing treatment duration, and limiting use of high-risk antibiotics like fluoroquinolones and cephalosporins as a way to prevent CDI. Many hospitals in HICs already report CDI rates to their national healthcare-associated infection tracking system, such as the US National Healthcare Safety Network (NHSN), as part of regulatory and reimbursement programs, making this a key metric to assess AMS impact. Since CDI prevention involves stewardship, microbiology, and infection control teams working closely together, monitoring CDI trends can help to fine-tune antibiotic prescribing, an important consequence of which is to reduce hospital-associated infections.

Another major focus of AMS is to reduce AMR by improving prescribing practices and minimizing unnecessary antibiotic exposure. Yet, the causes of AMR are multi-factorial, and its relationship with AMS interventions is complex. The most effective way to measure AMS impact on resistance is by tracking hospital-acquired resistant infections, particularly those that develop after admission, when patients are under the influence of hospital AMS policies. In the USA, for instance, many hospitals report AMR data through the NHSN Antimicrobial Resistance (AR) Option, which provides valuable benchmarking. Additionally, monitoring patient-level AMR trends, such as the percentage of patients developing resistant superinfections, helps AMS teams to assess whether interventions are successfully slowing the spread of multidrug-resistant pathogens.

Patient outcomes are indicators of the effectiveness of the ASP, ensuring that measures to reduce antibiotic use do not lead to unintended harm. Key clinical indicators include in-hospital mortality, infection-specific mortality, length of patient in-hospital stay, and 30-day readmission rate. Mortality tracking data help to confirm that AMS interventions do not compromise survival, while length of stay monitoring ensures that stewardship strategies do not inadvertently prolong hospitalizations. Readmission rates within 30 days serve as a critical checkpoint, as they indicate whether shortened antibiotic courses or de-escalation strategies are leading to infection recurrence.

1. **Education and Training**
2. *Introduction*

Education is essential for improving hospital antibiotic use, but on its own it is not sufficient to drive AMS success. It must be integrated with real-time feedback, policy enforcement, and outcome measurement. Effective methods include didactic sessions, electronic messaging, posters, newsletters, and case-based discussions, the most impactful of which involve direct engagement, such as PAF and preauthorization. Training should help hospitalists, nurses, and pharmacists to receive targeted information relevant to their responsibilities. Patient education is equally important — patients should understand why they are receiving antibiotics, potential side effects, and when to seek medical attention. When combined with other AMS strategies, education reinforces responsible antibiotic use and improves patient safety.

1. *Healthcare worker education*

Physician education should be integrated at multiple levels, from pre-service training in medical curricula and textbooks to mandatory or voluntary in-service training through continuing medical education programs. AMS-linked infection prevention and control training should also be incorporated into both formal and on-the-job learning, reinforcing the connection between antibiotic stewardship and hospital infection control practices.

A variety of educational approaches can be used to support physician learning. Face-to-face workshops provide structured training aligned with AMS competencies. Blended learning combines classroom instruction with online modules, enabling more flexible engagement of learners to fit around their busy healthcare workload. Electronic learning platforms offer another scalable solution, enabling access to local, national, and international AMS resources. However, interactive, case-based learning to apply knowledge in real-world scenarios is often the most impactful. Practical training at AMS centers of excellence and mentorship programs can further enhance learning by exposing physicians to successful stewardship models in different healthcare settings.

On-the-job training remains one of the most valuable and sustainable methods of physician education. Daily ward rounds with AMS teams provide real-time learning opportunities, allowing providers to discuss antibiotic decisions, review cases, and refine prescribing practices. For example, an AMS team may encounter a sepsis patient placed on broad-spectrum antibiotics (piperacillin/tazobactam) despite culture results showing susceptibility to amoxicillin. A brief discussion with attending physicians and nurses can highlight the rationale for guideline-based empirical therapy, the risks of broad-spectrum antibiotic overuse, and the benefits of de-escalation and IV-to-oral switching. These case-based discussions during ward rounds promote collaborative learning and reinforce AMS principles in real-time clinical decision-making. By integrating structured training, hands-on learning, and digital resources, ASPs can facilitate the building of a well-educated workforce that is equipped to drive effective AMS in hospitals.

1. *Patient education*

Educating patients and the broader community about AMS is essential to reducing inappropriate antibiotic use and raising awareness of AMR. As is entirely reasonable, many patients do not understand against which pathogens and under what circumstances antibiotics are effective, such that they often expect to receive or request antibiotics for viral infections like the common cold or influenza. Public education campaigns, patient-centered discussions, and community outreach programs can help to correct misconceptions and empower individuals to make informed decisions about antibiotic use. When patients understand the risks of unnecessary antibiotic use, including side effects, AMR development, and the disruption of normal gut microbiota, they are more likely to follow proper antibiotic guidelines and avoid demanding antibiotics when they are not needed.

In-hospital patient education should be integrated as a routine aspect of clinical care. Patients should know why they are receiving antibiotics, how to take them correctly, and what are the potential side effects. Nurses often provide real-time guidance on antibiotic indications, duration, and possible adverse effects. Patients should be advised not to share antibiotics, avoid leftover medications, and complete the prescribed course unless instructed otherwise by their provider. Additionally, patients should be warned of possible delayed antibiotic reactions that may occur even after completing therapy.

Beyond education of individual patients, community-wide awareness campaigns are critical in changing public perceptions and behaviors regarding antibiotic use. Government agencies, healthcare institutions, and AMS organizations can seek to collaborate on media campaigns, school-based education programs, and pharmacist-led counseling initiatives. Messaging should focus on simple, actionable points, such as “Not all infections need antibiotics”, “Antibiotics do not work for colds or flu”, and “Misusing antibiotics leads to resistance”. By integrating AMS principles into public health initiatives, community members can become active participants in combating AMR, reinforcing responsible antibiotic use across healthcare settings and in everyday life.

1. *Training content for physicians*
2. Antibiotics

* Understanding different antibiotic classes, for example, the spectrum of activity and mechanism of action of commonly prescribed antibiotics. Appreciating the clinical relevance of different antibiotic classes allows for appropriate selection based on infection type, severity, and suspected pathogens. This knowledge helps to prevent inappropriate prescribing, unnecessary broad-spectrum antibiotic use, and the development of AMR.
* Pharmacokinetics, pharmacodynamics, and patient-specific considerations for antibiotic selection, dosing, and administration, especially relating to special patient populations (pediatrics, pregnant or breastfeeding women, individuals with renal impairment, and obese patients). A strong understanding of drug absorption, distribution, metabolism, and excretion is critical to preventing under- or over-dosing and optimizing patient outcomes.
* Principles of antibiotic prescribing: prophylactic, empirical, and definitive therapy. Physicians should know when antibiotics are necessary (e.g., bacterial infections) and when they are not (e.g., viral infections, bacterial colonization). They must recognize that some infections, such as abscesses or foreign body infections, may not require antibiotic therapy and instead benefit from surgical intervention. When prescribing, physicians must assess infection severity, site, probable causative bacteria, and local antibiotic susceptibility patterns to choose the most appropriate antibiotic, dose, duration, and administration route.
* Documentation and communication in antibiotic use: all antibiotic prescriptions should include agent, dose, route, indication, duration, and review dates, recorded in medical records and transfer notes. Physicians should be skilled in patient communication to help them understand why an antibiotic is or is not needed, how it is taken correctly, and potential side effects. Educating patients on safe antibiotic use, adherence, and expectations helps to prevent misuse and supports better health outcomes.
* Managing antibiotic allergies, cross-reactions, and adverse effects. Awareness of, and distinguishing between, the different types of allergic reactions — such as immediate hypersensitivity, severe adverse reactions (e.g., Stevens-Johnson syndrome), and beta-lactam cross-reactions — is essential for safe prescribing. Monitoring for side effects like CDI, *Candida* superinfections, and microbiota disruption is important to prevent possible complications. When adverse effects occur, proper documentation in patient records, timely reporting, and appropriate intervention are necessary to protect patient safety and guide future prescribing decisions.

1. Microbiology

* Differentiating colonization and infection in order to avoid overuse of antibiotics, antibiotic resistance, and unneeded side effects. Colonization occurs when bacteria are present without causing disease, while infection involves inflammation, an immune response, and clinical symptoms. Colonization, such as the presence of bacteria in urine without UTI symptoms or bacteria on the skin without signs of infection, does not need treatment, while infections often require appropriate antibiotic therapy.
* Common causative agents and resistance mechanisms. Physicians should be familiar with Gram-positive and Gram-negative bacteria, including WHO-priority pathogens and *C. difficile*, which are major contributors to hospital-acquired infections and AMR. Recognizing common antibiotic resistance mechanisms in a healthcare setting helps to guide empirical therapy choices and infection control strategies. Utilizing cumulative antibiogram data brings an awareness of longitudinal AMR patterns and susceptibility trends in a healthcare facility, which is crucial to selecting appropriate empirical therapy.
* Proper collection, handling, and interpretation of microbiology samples are each an essential procedural step to provide accurate antimicrobial susceptibility results. Physicians should ensure that blood, urine and sputum samples, wound swabs, and other patient samples for diagnostic culture and screening are collected using a guideline-recommended technique to prevent contamination and diagnostic errors. Timely processing of microbiology samples and accurate communication of susceptibility results enable early de-escalation or modification of antibiotic therapy. In order to optimize patient care, physicians must be able to correctly interpret common diagnostic tools such as biomarkers, point-of-care tests, and antimicrobial susceptibility testing results.
* Selective sensitivity reporting and antibiograms help to reduce unnecessary broad-spectrum antibiotic use by limiting the number of antibiotics reported on susceptibility testing to only the most relevant options. Antibiograms, which summarize local resistance patterns and susceptibility data, are essential tools for guiding empirical antibiotic therapy and monitoring AMR trends. Understanding and correctly interpreting antibiograms enables physicians to make evidence-based prescribing decisions that minimize AMR development.
* Bug-drug combination charts (showing common pathogen-drug relationships). So-called ‘bug-drug’ combination charts provide a structured guide to match causative microorganisms with their recommended treatments, thereby helping to avoid unnecessary broad-spectrum antibiotic use. Proper use of these charts supports more precise prescribing, ensuring that patients receive the most effective and targeted therapy while reducing the risk of AMR and treatment failures.

1. AMS interventions

* Performing AMS interventions: key elements include adjusting antibiotic doses for patients with renal impairment and knowing from where to seek guidance on dose modifications. Monitoring antibiotic levels is essential for drugs requiring TDM, and physicians must be aware of the appropriate tests and interpretation methods. Regular antibiotic reviews — particularly at 48–72 hours in hospitalized patients — allow for timely reassessment of therapy, helping to discontinue unnecessary antibiotics or modify treatment based on clinical progress and microbiology results. AMS interventions also include IV-to-oral switching, thus ensuring that antibiotics are transitioned to oral formulations whenever clinically appropriate, which reduces hospital stay duration and the risks associated with IV therapy. Furthermore, physicians must be prepared to de-escalate therapy to a narrower-spectrum antibiotic when possible or to escalate treatment if the patient’s clinical condition or microbiology results indicate the need for broader coverage. Stopping antibiotic therapy entirely when no infection is evident is a critical aspect of AMS, preventing unnecessary antimicrobial exposure and AMR development.

Assessing an ASP for a structured approach to data collection, analysis, and feedback. Physicians must be familiar with AMS indicators, including structural, process, and outcome measures, and understand how to identify and interpret relevant data sources. Point prevalence surveys are valuable tools for assessing antimicrobial prescribing trends and compliance with stewardship guidelines. Physicians should also be able to measure antibiotic use metrics, such as DDD and DOT, and ensure that feedback on prescribing practices is timely and actionable. Engaging with local or national quality measures for antibiotic use — such as compliance with prescribing guidelines, frequency of 48–72 hour antibiotic reviews, and monitoring adverse events — is key to driving improvements. Additionally, physicians should understand the principles of AMR surveillance and the role of surveillance data in shaping AMS policies. Implementing balancing measures is crucial to ensure AMS interventions do not negatively impact patient outcomes, such as under-treatment of infections. A well-functioning ASP requires continuous evaluation, performance monitoring, and reporting, which together ensure that stewardship efforts lead to sustained improvements in antibiotic use and patient safety.

1. **Harnessing Artificial Intelligence and Machine Learning**

On a final note, artificial intelligence (AI) and machine learning deserve mention, the emergence of which is set to significantly enhance ASPs. In some well-resourced settings in HICs, this transformation is already revolutionizing AMS by enabling data-driven decision-making, improving diagnostic accuracy, and optimizing antibiotic use. When adopted more widely, these technologies hold immense potential to combat AMR and improve global health outcomes [16]. Some of these steps and the impact they have are outlined below:

1. *Predictive analytics for AMR.* AI models can analyze large datasets, including patient records, microbiological data, and treatment outcomes, to predict the likelihood of AMR for specific pathogens. This helps physicians choose the most effective antibiotics, reducing the risk of treatment failure and the spread of resistant strains.
2. *Optimizing antibiotic prescribing.* Machine learning algorithms can recommend personalized antibiotic regimens based on patient-specific factors such as age, comorbidities, infection type, and local AMR patterns. This reduces overuse and misuse of broad-spectrum antibiotics, promoting targeted therapy and minimizing side effects.
3. *Early detection of infections.* AI can analyze EHRs, microbiology results, and imaging data to detect infections earlier than traditional methods. Early intervention facilitates timely and appropriate antibiotic use, improving patient outcomes and reducing the need for prolonged or aggressive treatments.
4. *Monitoring and surveillance.* AI-powered tools can continuously monitor hospital data to identify trends in antibiotic use and resistance patterns. This enables real-time adjustments to AMS strategies and helps public health officials to track AMR on a larger scale.
5. *Decision support systems.* AI-driven clinical decision support systems provide real-time recommendations to healthcare providers during patient care. These systems ensure adherence to AMS guidelines and improve the quality of antibiotic prescribing.
6. *Reducing diagnostic uncertainty.* AI can assist in interpreting complex diagnostic tests, such as genomic sequencing or mass spectrometry, to identify pathogens and resistance markers more accurately. Faster and more accurate diagnostics reduce the reliance on empiric antibiotic therapy, which often leads to overuse.
7. *Cost and resource optimization.* By streamlining workflows and reducing unnecessary antibiotic use, AI can lower healthcare costs and free up resources for other critical areas. Hospitals can allocate resources more efficiently, improving overall patient care.
8. *Global AMR surveillance.* AI can integrate data from multiple sources, including hospitals, diagnostic and research laboratories, and public health databases, to create global AMR surveillance networks. This facilitates the early detection of emerging AMR patterns and informs international AMS efforts.

While AI models and machine learning algorithms offer significant benefits, there are key challenges to their implementation in ASPs. These considerations include:

* *Data quality:* AI models require high-quality, standardized data to function effectively.
* *Ethical concerns:* ensuring patient privacy and addressing biases in AI algorithms are critical.
* *Integration:* seamless integration with existing healthcare systems is necessary for widespread adoption.
* *Training:* healthcare providers need training to effectively use AI tools.

Future directions include:

* *Personalized medicine:* AI will enable more tailored antibiotic therapies based on individual patient profiles.
* *Advanced diagnostics:* integration of AI with next-generation diagnostics will further enhance precision in treatment.
* *Global collaboration:* AI-driven platforms will facilitate international cooperation in combating AMR. This worldwide level of coverage and cooperation is contingent on greater adoption of AI in healthcare systems, particularly those in LMICs currently confronted by structural difficulties [17].

1. **Conclusions**

ASPs enhance healthcare quality and safeguard access to effective antibiotics for future generations. While new generation stewardship techniques and strategies are on the horizon, ASPs continue to play a vital role in combating AMR, improving patient outcomes, and optimizing antibiotic use. Effective AMS relies on leadership support, interdisciplinary collaboration, and physician training to ensure responsible prescribing. In healthcare settings, implementing effective interventions is the most direct way to reduce antibiotic resistance, improve treatment effectiveness, and avoid complications associated with drug-resistant microorganisms. Providing healthcare professionals workplace training and online learning to understand AMS principles is a worthy investment in time and money as it improves patient care in the long term and helps to reduce the prevalence of AMR in both the health facility and the local community that it serves. Monitoring and evaluation drive AMS success, using metrics like DDD, DOT, AMR trends, and patient safety outcomes. Real-time data collection and feedback refine strategies and support ongoing improvements. With institutional and global commitment, AMS can reduce AMR, improve treatment outcomes, and ensure antibiotics remain effective for years to come.

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