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## Review Article

### Antibiotic Usage Trends and Rationality in Clinical Practice: A Narrative Review

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#### ABSTRACT

*Antibiotics have transformed clinical medicine by making previously life-threatening bacterial infections treatable and by enabling complex procedures, transplantation, cancer therapy and intensive care. However, antibiotic exposure is also a major selective pressure for antimicrobial resistance (AMR), particularly when antibiotics are used without a clear bacterial indication, when broad-spectrum agents are chosen unnecessarily, or when dose, route and duration are inappropriate. This narrative review synthesizes the antibiotic-focused content of the undergraduate project "Evaluation of Antibiotic Usage Trends and Rationality in Clinical Practise" with contemporary evidence and stewardship guidance. The review summarizes the principal antibacterial classes— $\beta$ -lactams, tetracyclines, fluoroquinolones, sulfonamides, macrolides, glycopeptides/lipoglycopeptides and aminoglycosides—with emphasis on mechanisms, clinical roles, safety considerations and resistance mechanisms. It then examines determinants of irrational use, including diagnostic uncertainty, empirical prescribing without microbiological support, self-medication, inappropriate fixed-dose combinations, excessive use of Watch antibiotics, inadequate documentation, patient expectations, limited access to diagnostics and weak antimicrobial stewardship infrastructure. Current evidence supports a structured approach based on syndrome recognition, severity assessment, microbiological sampling where appropriate, local susceptibility data, patient-specific factors, the WHO Access–Watch–Reserve (AWaRe) framework, timely review and de-escalation. India faces a particularly important stewardship challenge because of high antibiotic consumption, substantial community access and heterogeneous regulatory and healthcare environments. Effective stewardship therefore requires coordinated action by prescribers, pharmacists, microbiologists, nurses, administrators, regulators and patients, supported by surveillance, infection prevention, diagnostics and public education. The central message is that rational antibiotic use is not antibiotic restriction: it is the delivery of the right antibiotic, at the right dose, by the right route, for the right duration, only when the expected clinical benefit outweighs the individual and population-level harms.*

**Keywords:** Antibiotics; Antimicrobial Resistance; Antibiotic Consumption; Rational Prescribing; Antimicrobial Stewardship; Aware; Self-Medication; India; Antibiotic Resistance; Clinical Practice.

## Introduction

Antibiotics are antibacterial medicines that either inhibit bacterial growth or kill susceptible bacteria. The project on which this review is based describes antibiotics as a major therapeutic advance and traces the modern antibiotic era from the work of Paul Ehrlich and the discovery of penicillin by Alexander Fleming, followed by the clinical development of penicillin and the discovery of streptomycin. The project emphasizes that antibiotics remain essential for respiratory, urinary, gastrointestinal, skin, bloodstream and other bacterial infections [1].

The clinical value of antibiotics is inseparable from the problem of resistance. Antimicrobial resistance occurs when microorganisms acquire or express mechanisms that reduce susceptibility to medicines. In bacteria, resistance can arise through mutation, acquisition of resistance genes, horizontal gene transfer and selection under antimicrobial pressure. WHO currently identifies AMR as a major global health threat and reports that bacterial AMR was associated with more than 4.7 million deaths globally in 2021; approximately one in six laboratory-confirmed bacterial infections in 2023 was resistant to antibiotic treatment [2].

Antibiotic use is therefore a clinical decision with consequences beyond the individual prescription. A patient may benefit from treatment, while unnecessary exposure can select resistant organisms, disturb the microbiome, cause adverse drug reactions and increase healthcare expenditure. At population level, inappropriate antibiotic use can accelerate resistance and reduce the future effectiveness of essential medicines. A systematic review of antibiotic consumption and resistance found a positive association between consumption and resistance in most evaluated relationships, reinforcing the importance of reducing unnecessary exposure [3].

The original project highlights self-medication, over-prescription, incomplete treatment and antibiotic use in agriculture as important contributors to resistance, and emphasizes stewardship, infection prevention and public education [4]. The present review expands that framework using current WHO guidance and recent literature, with particular attention to clinical rationality and practical stewardship.

## Review Approach

This article is a narrative review developed from the uploaded undergraduate project and supplemented with contemporary authoritative and peer-reviewed sources. The project provided the core organization of antibiotic classes, mechanisms of action, therapeutic

roles, adverse effects, resistance concepts and literature-review themes. Current external evidence was used to update the discussion of AMR burden, antibiotic consumption, AWaRe classification, stewardship, surveillance and the Indian context.

## Antibiotic Classes and Clinical Significance

The project reviews several major antibiotic classes according to chemical structure, spectrum and mechanism. The most clinically important mechanisms can be grouped into inhibition of cell-wall synthesis, inhibition of protein synthesis, inhibition of nucleic-acid synthesis and interference with essential metabolic pathways [5].

### $\beta$ -Lactam Antibiotics

$\beta$ -Lactams remain foundational antibacterial agents. The project describes penicillins, cephalosporins, carbapenems, monobactams and  $\beta$ -lactamase inhibitors and explains that  $\beta$ -lactams inhibit the final transpeptidation step in peptidoglycan synthesis by acylating penicillin-binding proteins, ultimately impairing cell-wall integrity and promoting bacterial lysis [6].

From a stewardship perspective, the large  $\beta$ -lactam family illustrates why class-level thinking is insufficient. A narrow-spectrum penicillin may be appropriate for a susceptible infection, whereas a carbapenem should generally be reserved for situations in which the expected pathogen or resistance profile justifies its broader activity. The clinical objective is not simply to select an active drug but to select the narrowest effective agent supported by the syndrome, severity, local epidemiology and microbiology.

$\beta$ -Lactams are generally well tolerated, but hypersensitivity reactions, renal effects with selected agents, neurological toxicity at excessive exposure and drug-specific adverse effects must be considered. The project also notes important safety issues involving selected cephalosporins and carbapenems [7].

### Tetracyclines

Tetracyclines are broad-spectrum agents that include older tetracyclines and newer agents such as doxycycline and omadacycline. The project describes their inhibition of the 30S ribosomal subunit, preventing aminoacyl-tRNA binding and thereby suppressing bacterial protein synthesis [8].

Rational prescribing requires attention to age, pregnancy status, indication, gastrointestinal tolerability and interactions. The project notes that

polyvalent cations such as calcium, magnesium, iron and aluminium can reduce absorption by chelation, and it describes gastrointestinal effects, photosensitivity,

dental effects in children, hepatotoxicity and intracranial hypertension as clinically relevant considerations [9].

**Table 1:** Major antibiotic classes and principles relevant to rational clinical use.

| Class                             | Principal target/mechanism                                       | Representative agents                                                   | Key rational-use considerations                                                                                             |
|-----------------------------------|------------------------------------------------------------------|-------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------|
| $\beta$ -lactams                  | Penicillin-binding proteins; inhibit peptidoglycan cross-linking | amoxicillin, cefazolin, ceftriaxone, piperacillin–tazobactam, meropenem | Choose narrowest effective spectrum; adjust for allergy/renal function; avoid unnecessary carbapenems                       |
| Tetracyclines                     | 30S ribosomal subunit; inhibit aminoacyl-tRNA entry              | doxycycline, minocycline, tetracycline                                  | Useful for selected atypical and intracellular infections; consider age, pregnancy and interactions with polyvalent cations |
| Fluoroquinolones                  | DNA gyrase and topoisomerase IV                                  | ciprofloxacin, levofloxacin, moxifloxacin                               | High stewardship priority because of resistance and important adverse effects; reserve for appropriate indications          |
| Sulfonamides                      | Dihydropteroate synthase; folate pathway inhibition              | sulfamethoxazole, sulfadiazine                                          | Often used with trimethoprim; consider allergy, renal function and drug interactions                                        |
| Macrolides                        | 50S ribosomal subunit; inhibition of protein synthesis           | azithromycin, clarithromycin, erythromycin                              | Useful for selected respiratory/atypical infections; monitor resistance and QT/drug-interaction risks                       |
| Glycopeptides / lipoglycopeptides | Bind cell-wall precursors and inhibit peptidoglycan assembly     | vancomycin, teicoplanin, dalbavancin                                    | Primarily Gram-positive; therapeutic monitoring and renal safety are important for selected agents                          |
| Aminoglycosides                   | 30S ribosome; misreading/inhibition of protein synthesis         | gentamicin, amikacin, tobramycin                                        | Concentration-dependent killing but nephrotoxicity/ototoxicity require careful dosing and monitoring                        |

### Fluoroquinolones

Fluoroquinolones inhibit bacterial DNA gyrase and topoisomerase IV. The project describes their historical development from nalidixic acid and their broad activity against important Gram-negative and selected Gram-positive pathogens [10].

The broad spectrum and convenient oral bioavailability of fluoroquinolones can make them attractive prescribing choices, but these same features can promote overuse. Rational use requires clear indication, consideration of local resistance, review of alternatives and attention to adverse effects. The project lists gastrointestinal, central nervous system, hepatic, photosensitivity and QT-related concerns [11].

### Sulfonamides

Sulfonamides are synthetic antibacterial agents that interfere with folate synthesis by acting as structural analogues of para-aminobenzoic acid. The project explains their inhibition of dihydropteroate synthetase and the rationale for combining sulfonamides with trimethoprim to block sequential steps in folate metabolism [12].

### Macrolides

Macrolides such as erythromycin, clarithromycin and azithromycin act mainly at the bacterial 50S ribosomal subunit and inhibit protein synthesis. The project describes their use in respiratory and atypical infections and their additional immunomodulatory properties [13].

Macrolide resistance can emerge through target-site modification, including methylation of 23S rRNA, as well as other mechanisms. Their use should therefore

be driven by a valid clinical indication and local susceptibility patterns rather than by the assumption that a convenient oral broad-spectrum drug is universally appropriate. QT prolongation, gastrointestinal effects and drug interactions are important safety considerations [14].

### **Glycopeptides and Lipoglycopeptides**

Vancomycin and related agents target Gram-positive organisms by binding cell-wall precursors and interfering with peptidoglycan assembly. The project describes binding to the D-alanyl-D-alanine terminus of lipid II and the consequent inhibition of transglycosylation and transpeptidation [15].

These agents are important for selected serious Gram-positive infections, including infections caused by resistant organisms. Their use should be closely linked to microbiological evidence, local epidemiology and appropriate monitoring because unnecessary exposure increases toxicity, selection pressure and resource use.

### **Aminoglycosides**

Aminoglycosides such as gentamicin, amikacin and tobramycin are bactericidal inhibitors of bacterial protein synthesis. The project describes concentration-dependent activity and their important role against susceptible Gram-negative organisms [16].

Because aminoglycosides have narrow therapeutic margins and clinically important nephrotoxicity and ototoxicity, rational use requires accurate weight-based dosing, renal-function assessment and therapeutic drug monitoring when indicated. Their value is greatest when their pharmacodynamic advantages outweigh these risks.

### **Antibiotic Use and the Development of Resistance**

Resistance is a biological response to antimicrobial selection rather than a simple consequence of a single inappropriate prescription. Resistant organisms may pre-exist at low frequency, arise through mutation, acquire resistance genes through horizontal gene transfer or be selected and amplified during antibiotic exposure. The project recognizes misuse and overuse as central drivers and highlights the importance of surveillance, rational prescribing and public awareness [17].

Major bacterial resistance mechanisms include enzymatic drug inactivation, modification of the antimicrobial target, reduced permeability, active efflux and metabolic bypass. Examples include  $\beta$ -lactamases that hydrolyse  $\beta$ -lactam agents, altered penicillin-binding proteins, target modification in macrolide resistance, efflux systems affecting tetracyclines and mutations affecting fluoroquinolone targets. Resistance mechanisms can accumulate in the same organism, producing multidrug-resistant phenotypes.

The clinical consequences include treatment failure, delayed effective therapy, longer hospitalization, increased need for invasive diagnostics, greater toxicity from second-line agents and higher costs. WHO's 2025 global surveillance report analyzed more than 23 million bacteriologically confirmed cases reported by countries and provides evidence that standardized surveillance is essential for identifying resistance trends and guiding action [18].

### **Patterns And Determinants of Irrational Antibiotic Use**

Rational antibiotic therapy requires alignment among diagnosis, pathogen, drug, dose, route, duration and patient-specific characteristics. Irrational use occurs when one or more of these elements is inappropriate. The problem is multifactorial and cannot be attributed solely to prescriber behaviour.

Self-medication is particularly important in settings where antibiotics can be obtained with limited clinical assessment. In India, national private-sector data for 2019 estimated 5071 million defined daily doses of systemic antibiotics, with Watch antibiotics accounting for 54.9% of consumption and Access antibiotics 27.0%. The investigators noted regulatory and availability complexities, including over-the-counter access and the proliferation of fixed-dose combinations [19].

The project similarly emphasizes self-medication, over-prescription, incomplete courses and non-clinical antibiotic exposure as major drivers of resistance [20]. These factors support a shift from viewing rationality as a prescriber-only issue toward a health-system model involving patients, pharmacists, diagnostic services, infection-control teams, regulators and public-health authorities.

**Table 2:** Major determinants of irrational antibiotic use and corresponding stewardship responses.

| Determinant                      | Typical manifestation                                         | Potential consequence               | Stewardship response                                                                     |
|----------------------------------|---------------------------------------------------------------|-------------------------------------|------------------------------------------------------------------------------------------|
| Diagnostic uncertainty           | Antibiotics prescribed for likely viral/self-limiting illness | Unnecessary exposure and resistance | Use clinical criteria, diagnostics and delayed/no-antibiotic strategies when appropriate |
| Broad-spectrum preference        | Watch/Reserve agent used when Access agent is adequate        | Higher selection pressure and cost  | Local guideline + AWaRe review                                                           |
| Empirical therapy without review | Initial regimen continued despite culture results             | Missed de-escalation                | 48–72 h antibiotic time-out                                                              |
| Self-medication                  | Use of old prescriptions or another person's antibiotics      | Wrong drug/dose; delayed diagnosis  | Public education and pharmacy engagement                                                 |
| Inadequate documentation         | No indication, duration or stop/review date                   | Continuation errors                 | Standard antibiotic prescription fields                                                  |
| Patient expectations             | Perceived need for “strong” antibiotics                       | Unnecessary prescribing             | Communication and symptomatic-care advice                                                |
| Limited diagnostics              | Empiric treatment dominates                                   | Uncertain pathogen-directed therapy | Strengthen microbiology and point-of-care diagnostics                                    |
| Poor infection prevention        | Healthcare-associated infections continue to occur            | Higher antibiotic demand            | Hand hygiene, vaccination, IPC bundles                                                   |
| Fragmented regulation            | Easy access to antibiotics and variable enforcement           | Community overuse                   | Prescription controls and surveillance                                                   |

### WHO AWaRe Classification and Its Role in Rational Prescribing

The WHO AWaRe framework classifies antibiotics into Access, Watch and Reserve groups according to their importance, spectrum and potential contribution to resistance. Access agents generally have a lower resistance potential and are preferred first-line options for many common infections; Watch agents have a higher resistance potential and should have more restricted indications; Reserve agents are intended for

difficult-to-treat infections when alternatives are unsuitable [21].

AWaRe is not a substitute for clinical judgement or local guidelines. Rather, it provides a population-level framework for monitoring use and a practical reminder that broad-spectrum therapy should not automatically be considered superior therapy. WHO's current 2025 classification is intended to support monitoring, target-setting and evaluation of stewardship interventions [22].

**Table 3:** Practical interpretation of the WHO AWaRe framework.

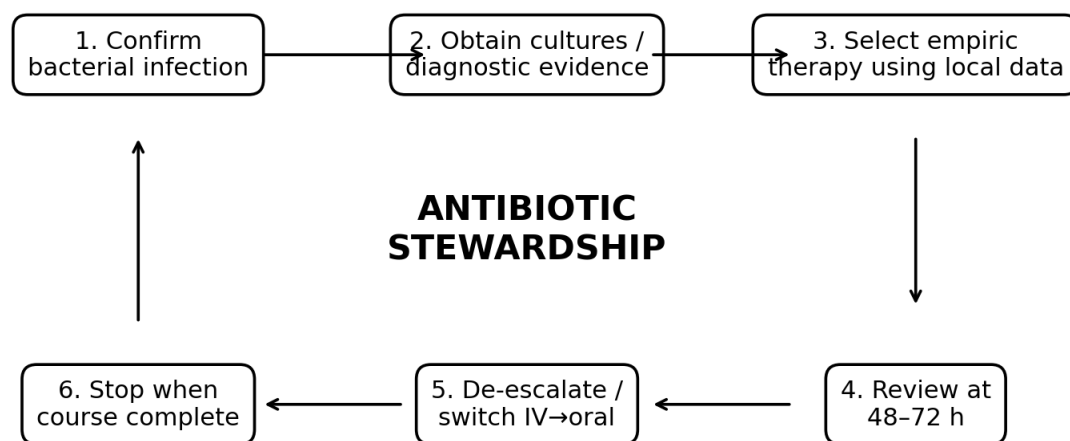
| AWaRe group | Core principle                                                                                 | Clinical implication                                            | Monitoring priority                                |
|-------------|------------------------------------------------------------------------------------------------|-----------------------------------------------------------------|----------------------------------------------------|
| Access      | Preferred first-choice agents for many common infections; generally lower resistance potential | Use when clinically appropriate and supported by local guidance | Increase proportion of appropriate Access use      |
| Watch       | Higher resistance potential and more limited empiric indications                               | Use only when indication, pathogen or severity justifies it     | Audit indication, dose, duration and de-escalation |
| Reserve     | Last-resort options for selected resistant infections                                          | Use with strong microbiological/clinical justification          | Restrict, review and monitor closely               |

WHO has also set a global direction toward increasing the proportion of antibiotic use represented by Access antibiotics. The 2025 GLASS guide notes a 2024

global target that at least 70% of national antibiotic use should come from the Access group [23]. This target should be interpreted alongside clinical

appropriateness: a higher Access share is desirable only when the chosen Access agents are appropriate

for the infections being treated.

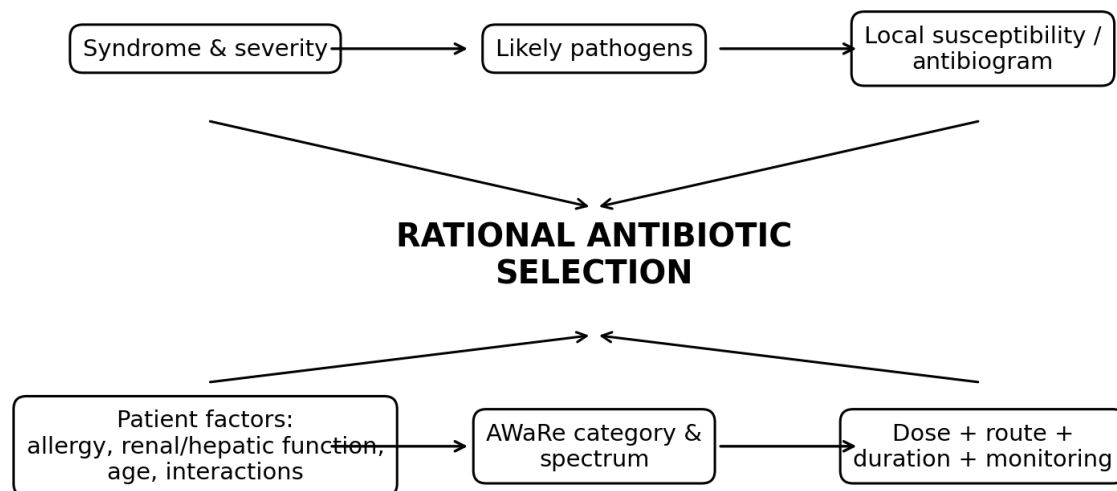


**Figure 1:** A practical antibiotic stewardship cycle for clinical practice.

### Principles of Rational Antibiotic Prescribing

Rational prescribing begins before the prescription is written. The first decision is whether an antibiotic is required at all. When a bacterial infection is unlikely, symptomatic management, observation or an

appropriate non-antibiotic strategy may be safer. When infection is likely or confirmed, the prescriber should define the syndrome and severity, identify likely pathogens, obtain cultures when clinically indicated, assess patient factors and choose therapy using current guidelines and local susceptibility data.



**Figure 2:** Multidimensional framework for rational antibiotic selection.

**Indication:** document the suspected or confirmed bacterial syndrome and why antibiotic treatment is warranted.

**Drug selection:** choose the narrowest effective spectrum consistent with severity, likely pathogen, resistance risk and local guidelines.

**Dose:** optimize exposure using patient weight, renal/hepatic function,

pharmacokinetic/pharmacodynamic principles and therapeutic drug monitoring where appropriate.

**Route:** use intravenous therapy when severity, absorption or source-control considerations require it; switch to oral therapy when clinically stable and an effective oral option exists.

**Duration:** prescribe the shortest evidence-based course that is adequate for the specific infection and patient.

**Microbiology:** obtain appropriate specimens before antibiotics when feasible and safe, without causing clinically important treatment delays in severe infection.

**Review:** reassess diagnosis, cultures, clinical response, adverse effects and organ function at a defined time point, commonly 48–72 hours.

**De-escalation:** narrow, stop, change or continue treatment according to the accumulated evidence.

**Documentation:** record indication, agent, dose, route, duration and review/stop date.

### **Antimicrobial Stewardship in Hospitals and Community Settings**

Antimicrobial stewardship (AMS) is a coordinated set of interventions designed to optimize antimicrobial use while improving patient outcomes and limiting adverse effects and resistance. WHO's AWARe antibiotic book provides evidence-based guidance on antibiotic choice, dose, route and duration for more than 30 common infections and is intended to complement rather than replace local or national guidance [24].

In hospitals, core stewardship interventions include prospective audit with feedback, formulary restriction/preauthorization for selected agents, facility-specific treatment guidelines, antibiotic time-outs, dose optimization, IV-to-oral conversion, surgical prophylaxis review, therapeutic drug monitoring and regular antibiogram updates. The National Action Plan on Antimicrobial Resistance in India specifically calls for antimicrobial stewardship programmes, regularly updated guidelines, multidisciplinary AMS teams and phased training and implementation [25].

Recent Indian evidence supports the feasibility of such programmes. A multicentre study across 11 Indian hospitals reported marked improvement in stewardship compliance following hospital-specific antibiograms, antibiotic policy implementation, consumption monitoring, staff training and audit-feedback. [cite]turnlsearch7 A recent scoping review also identified staff engagement, audit-feedback, administrative participation, documentation and interactive education as facilitators, while limited access, weak regulatory implementation and inadequate knowledge remained barriers [26].

Pharmacists have an important role because medication expertise allows them to identify inappropriate dose, duration, duplication, interactions and opportunities for de-escalation. A systematic review and meta-analysis found that pharmacist-led

stewardship interventions were associated with higher odds of appropriate antibiotic prescribing and faster time to appropriate therapy in emergency-department settings [27].

### **Diagnostics, Antibiograms and Surveillance**

One of the strongest determinants of rational prescribing is the quality of information available to the clinician. Microbiology cultures, susceptibility testing and facility-specific antibiograms can reduce reliance on generalized assumptions about resistance. An antibiogram summarizes local susceptibility patterns and can guide empiric therapy while supporting subsequent refinement.

A systematic review of antibiogram interventions identified their use as a stewardship strategy intended to optimize antimicrobial prescribing and patient outcomes [28]. However, an antibiogram is only as useful as the quality of the underlying laboratory data and the extent to which clinicians can translate the information into practical prescribing decisions.

Surveillance should combine antibiotic-use data with resistance data. Useful indicators include defined daily doses per 1000 patient-days, days of therapy, Access/Watch/Reserve distribution, culture positivity, resistance rates, guideline concordance, surgical prophylaxis duration, IV-to-oral conversion, antimicrobial expenditure and clinical outcomes. WHO's GLASS programme emphasizes that surveillance data should be translated into action rather than collected as an administrative exercise.

### **Special Problems in the Indian Context**

India represents a complex stewardship environment because antibiotic use occurs across public hospitals, private hospitals, clinics, pharmacies and informal care pathways. The 2019 private-sector consumption analysis identified substantial use of Watch antibiotics and highlighted challenges related to access, fixed-dose combinations and regulatory overlap.

At the same time, the solution cannot be simple restriction. Patients require timely access to effective antibiotics for genuine bacterial infections, especially in severe disease. Stewardship must therefore balance two responsibilities: preventing unnecessary antibiotic exposure and preventing under-treatment of serious infections. This balance is particularly important in resource-constrained settings where diagnostic services may be limited.

India's National Action Plan on AMR provides a policy framework that includes surveillance of

antimicrobial use, compliance with standard treatment guidelines and development of multidisciplinary stewardship programmes. Implementation at facility and district levels remains essential for translating national objectives into prescribing behaviour.

### **Patient, Pharmacist and Public Engagement**

Patient communication is a practical stewardship intervention. A clinician explains why an antibiotic is not required, what symptoms should prompt reassessment and how symptomatic treatment works may reduce the perceived need for antibiotics. For patients receiving antibiotics, clear instructions about dose, timing, interactions, missed doses and the reason for treatment improve safe use.

The project recommends that patients should not use another person's antibiotics or old leftover medicines and should follow the prescribed regimen. It also highlights infection-prevention behaviours such as hand hygiene and appropriate masking. These messages should be reinforced by pharmacists, nurses, community health workers and public-health campaigns.

Pharmacies can contribute through prescription verification, patient counselling, referral of red-flag symptoms and avoidance of inappropriate antibiotic dispensing. Community-level stewardship should also address expectations for injections and broad-spectrum medicines, misconceptions that antibiotics treat viral illnesses, and the practice of keeping leftover antibiotics at home.

### **Infection Prevention as an Antibiotic-Saving Strategy**

Every infection prevented is an antibiotic course potentially avoided. Hand hygiene, environmental cleaning, vaccination, safe water and sanitation, respiratory hygiene, appropriate isolation, device-care bundles and surgical infection prevention reduce the incidence and transmission of infections. The project literature review highlights the importance of hand hygiene and infection-control measures as components of antimicrobial stewardship [29].

Stewardship and infection prevention should therefore be integrated rather than managed as separate programmes. A hospital with poor infection control may attempt to compensate with increasing antibiotic use, which can create a cycle of selection and transmission of resistant organisms. Conversely, effective infection prevention reduces the need for antibiotics and protects the remaining effectiveness of available drugs.

### **The Microbiome and Other Unintended Consequences**

Antibiotics do not act only on pathogens. They can alter the human microbiome, sometimes substantially, depending on drug, spectrum, route, dose and duration. The project literature review notes concerns regarding disruption of beneficial microorganisms and the importance of cautious antibiotic use.

Additional harms include allergic reactions, gastrointestinal disturbances, drug interactions, organ toxicity and *Clostridioides difficile* infection. These effects reinforce a fundamental stewardship principle: when the expected benefit of an antibiotic is small or uncertain, even a well-tolerated drug can have an unfavourable risk–benefit balance.

### **Proposed Clinical Audit Framework**

The project topic is explicitly concerned with evaluating antibiotic usage trends and rationality. A practical next step for clinical institutions is a repeated prescription audit using standardized indicators. The following framework can convert the conceptual review into a measurable quality-improvement programme.

### **Discussion**

The central issue emerging from the project and contemporary evidence is that antibiotic rationality is multidimensional. The choice of drug alone cannot define appropriate therapy. A prescription may contain an active antibiotic yet remain irrational if the diagnosis is incorrect, the spectrum is unnecessarily broad, the dose is inappropriate, the route is unnecessarily invasive or the duration is excessive. Conversely, an apparently broad-spectrum regimen may be justified temporarily in a severely ill patient with a high risk of resistant infection if it is promptly reviewed and narrowed when evidence becomes available.

The project's literature review repeatedly links antibiotic consumption with resistance and emphasizes surveillance, public awareness and stewardship [30]. Contemporary evidence strengthens this argument: WHO reports that inappropriate use and overuse remain major drivers of AMR, while recent global surveillance demonstrates the scale of resistance across common infections [31].

India-specific data also show why stewardship must address both prescribing and access. High consumption of Watch antibiotics in the private sector indicates that simply increasing antibiotic availability

is not sufficient; the health system must improve diagnosis, guideline use, monitoring and communication [32].

Importantly, stewardship should be evaluated using patient-centred outcomes. Reducing antibiotic use is not itself a success if it causes delayed treatment or poorer outcomes. The best programmes improve

appropriateness while maintaining or improving mortality, length of stay, readmission, adverse events and patient satisfaction. Evidence from Indian hospitals and pharmacist-led interventions suggests that well-designed stewardship programmes can improve prescribing quality without requiring indiscriminate restriction [33].

**Table 4:** Suggested indicators for evaluating antibiotic rationality in clinical practice.

| Domain       | Indicator                                                     | Suggested data source            | Interpretation                                          |
|--------------|---------------------------------------------------------------|----------------------------------|---------------------------------------------------------|
| Indication   | % prescriptions with documented indication                    | Prescription chart/EMR           | Higher documentation supports review and accountability |
| Choice       | % guideline-concordant agent                                  | Prescription + local guideline   | Measures drug-selection quality                         |
| AWaRe        | % Access/Watch/Reserve use                                    | Pharmacy dispensing/DDD/DOT      | Tracks spectrum and resistance pressure                 |
| Dose         | % dose appropriate for patient factors                        | Chart + renal/hepatic data       | Identifies under/overexposure                           |
| Route        | % eligible IV courses converted to oral                       | Medication administration record | Potential reduction in IV-related harm and cost         |
| Duration     | % courses within recommended duration                         | Prescription/EMR                 | Identifies prolonged therapy                            |
| Review       | % prescriptions reviewed at 48–72 h                           | Stewardship audit                | Measures active reassessment                            |
| Microbiology | % appropriate cultures obtained before therapy when indicated | Laboratory records               | Supports targeted therapy                               |
| Outcome      | Clinical response, LOS, readmission, adverse events           | Hospital information system      | Ensures stewardship does not compromise care            |

### Future Perspectives

Future stewardship will increasingly combine clinical decision support, rapid diagnostics, electronic prescribing, local antibiograms, real-time surveillance and pharmacy-led review. Artificial intelligence may assist with risk stratification and identification of potentially inappropriate prescriptions, but algorithmic recommendations should remain subordinate to clinical judgement and local microbiological evidence.

New antibiotics are important but cannot solve the resistance problem alone. The antibiotic development pipeline remains limited, and every new agent can eventually encounter resistance if used indiscriminately. The long-term strategy must therefore combine discovery with prevention, vaccination, diagnostics, infection control, stewardship and One Health approaches that address antimicrobial use in humans, animals, agriculture and the environment. WHO's current global action plan places appropriate antimicrobial use, surveillance, infection

prevention, research and multisectoral governance at the centre of the response.

### Conclusion

Antibiotics remain indispensable to modern clinical practice, but their effectiveness is threatened by inappropriate use and antimicrobial resistance. The project provides a useful foundation by reviewing major antibiotic classes, mechanisms, adverse effects, resistance and stewardship principles. Updated evidence demonstrates that the challenge is global and particularly relevant to settings such as India, where antibiotic consumption patterns, access pathways and diagnostic capacity vary substantially.

Rational antibiotic use should be understood as a structured clinical process: confirm that an antibiotic is needed; select an evidence-based agent with the narrowest suitable spectrum; optimize dose and route; define duration; obtain microbiological information when appropriate; reassess at 48–72 hours; and stop or

de-escalate when evidence permits. The WHO AWaRe framework, local treatment guidelines, antibiograms, antimicrobial stewardship teams, pharmacists, infection-control programmes and patient education can collectively support this process.

The ultimate goal is not simply to reduce antibiotic consumption but to maximize appropriate treatment and minimize avoidable harm. Preserving antibiotic effectiveness is a shared responsibility of prescribers, pharmacists, microbiologists, nurses, patients, health administrators, regulators and policymakers. Sustained surveillance and repeated clinical audit are essential to determine whether stewardship interventions translate into safer prescribing, better outcomes and lower resistance.

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### **Conflict of Interest**

None declared.

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