RESEARCH PAPER

Specialty-Specific Antimicrobial Stewardship in Hospitals: Evidence from Medicine, Surgery, Critical Care, and Oncology-A Systematic Review

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Abstract

Background

Antimicrobial stewardship programmes are established components of hospital quality and patient-safety systems. However, stewardship cannot be implemented identically across all clinical specialties. General medical wards frequently require correction of diagnostic uncertainty and excessive treatment duration; surgical services require optimisation of antimicrobial prophylaxis and source-control-related therapy; critical-care units require rapid empirical treatment followed by structured reassessment; and oncology services must balance antimicrobial reduction against the consequences of infection during neutropenia and immunosuppression.

Objective

This systematic review evaluated specialty-specific antimicrobial stewardship interventions in adult hospital practice. It compared their effects on antimicrobial prescribing, treatment duration, spectrum, route, surgical prophylaxis, diagnostic utilisation, antimicrobial resistance, *Clostridioides difficile* infection, adverse drug events, length of stay, readmission, treatment failure, and mortality across medicine, surgery, critical care, and oncology.

Methods

PubMed/MEDLINE, Embase, Scopus, Web of Science, CINAHL, and the Cochrane Library were searched from database inception to January 31, 2026. Additional studies were identified through Google Scholar, ClinicalTrials.gov, citation tracking, and reference-list screening. Randomised trials, prospective comparative studies, interrupted time-series analyses, and controlled before-and-after studies were eligible when they assessed a deliberate hospital intervention intended to optimise antimicrobial prescribing. Two reviewers independently screened records, extracted data, and assessed methodological quality. Substantial heterogeneity in interventions, specialties, antimicrobial measures, infection syndromes, and clinical outcomes precluded meta-analysis; therefore, a structured narrative synthesis was undertaken.

Results

The search identified 3,912 records, comprising 3,814 records from electronic databases and 98 from supplementary sources. After removal of 1,018 duplicates, 2,894 titles and abstracts were screened. A total of 2,651 records were excluded, and 243 reports were sought for retrieval. Nine reports could not be obtained, leaving 234 full-text reports for eligibility assessment. Of these, 206 were excluded for predefined reasons, and 28 studies were included in the qualitative synthesis. On medical wards, prospective audit, diagnostic reassessment, intravenous-to-oral conversion, and duration-focused interventions improved appropriateness and reduced antimicrobial exposure. Surgical interventions were most effective when prophylaxis guidelines were combined with automatic stop systems, audit, and surgeon-level feedback. In critical care, biomarker-supported discontinuation and daily review reduced treatment duration, but de-escalation required careful consideration of instability, source control, and microbiological reliability. In oncology, targeted restriction of vancomycin, risk-stratified outpatient treatment, and discontinuation of empirical therapy in selected stable patients reduced exposure without clear evidence of increased mortality or treatment failure. Effects on resistance were variable and generally less immediate than improvements in prescribing.

Conclusions

Antimicrobial stewardship is most effective when shared institutional principles are translated into specialty-specific clinical pathways. Programmes should preserve immediate effective treatment for severe infection while creating mandatory opportunities for diagnostic reassessment, narrowing, route conversion, dose optimisation, and discontinuation. Success depends on specialty ownership, pharmacy and microbiology support, reliable measurement, and monitoring of safety outcomes alongside antimicrobial consumption.

Keywords: antimicrobial stewardship; hospital medicine; surgical prophylaxis; intensive care; critical care; oncology; febrile neutropenia; antibiotic de-escalation; antimicrobial resistance; systematic review

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1. Introduction

Antimicrobial resistance reduces the reliability of treatment for common and severe infections and threatens the safety of surgery, cancer therapy, transplantation, intensive care, and other medical interventions. The global burden of bacterial antimicrobial resistance is substantial, with resistant infections contributing directly and indirectly to mortality across healthcare systems.[1]

Hospitals are major sites of antimicrobial exposure. Patients commonly receive empirical broad-spectrum therapy before infection has been confirmed or a pathogen has been identified. This practice is clinically justified when delayed treatment may cause serious harm, but continued exposure after diagnostic clarification can increase toxicity, *Clostridioides difficile* infection, drug interactions, microbiome disruption, colonisation with resistant organisms, and healthcare costs.

Antimicrobial stewardship refers to coordinated efforts to improve and measure antimicrobial use by optimising the agent, dose, route, and duration of treatment.[2,3] It is not synonymous with antimicrobial restriction. Appropriate stewardship may recommend immediate broad-spectrum treatment, higher doses, extended infusion, combination therapy, therapeutic drug monitoring, or escalation when the initial regimen is inadequate. The central objective is appropriate therapy rather than minimal therapy.

Hospital stewardship programmes generally operate through leadership commitment, accountable programme ownership, pharmacy expertise, clinical interventions, monitoring, reporting, and education. The CDC Hospital Core Elements describe these structural and procedural foundations, while the IDSA/SHEA guideline recommends pre-authorisation and prospective audit with feedback as core interventions.[2,4] WHO's AWaRe framework additionally supports monitoring of Access, Watch, and Reserve antibiotic use and provides guidance regarding agent selection, route, dose, and treatment duration.[5] These contemporary frameworks recognise stewardship as an adaptable hospital system rather than a single prescribing rule.

The clinical problem addressed by stewardship differs across specialties. In hospital medicine, excessive therapy frequently results from uncertain diagnoses, treatment of colonisation, failure to reassess empirical antibiotics, and unnecessarily long discharge prescriptions. Medical stewardship must therefore place substantial emphasis on diagnostic reasoning, syndrome-based pathways, treatment duration, and transition from inpatient to outpatient care.

In surgery, antimicrobial exposure arises through both prophylaxis and treatment. Prophylactic antibiotics are often administered too early or too late, selected without regard to procedure-specific flora, or continued after the period in which they provide benefit. Surgical stewardship must therefore address timing, redosing, weight-based dosing, discontinuation, source control, and differentiation between prophylaxis and treatment.

Critical-care practice requires a different balance. Delayed adequate antimicrobial therapy in septic shock may be fatal, while continued broad-spectrum exposure contributes to resistance, fungal infection, toxicity, and superinfection. Critical-care stewardship must protect early empirical treatment while ensuring high-quality cultures, pharmacokinetic optimisation, daily reassessment, source control, de-escalation, and timely discontinuation.

Oncology and haematology services also require rapid empirical therapy because infection may progress quickly during neutropenia. Nevertheless, routine addition of anti-MRSA therapy, prolonged treatment of culture-negative fever, unnecessary fluoroquinolone prophylaxis, and avoidable empirical antifungal treatment create significant stewardship opportunities. Risk stratification and clear safety criteria are essential.

These differences indicate that a single hospital policy is insufficient. Core stewardship principles should be common across the institution, but the decision thresholds, interventions, outcome measures, and safety safeguards must reflect the specialty and patient population.

1.1 Rationale

Previous stewardship reviews have frequently pooled interventions across hospital settings. Such synthesis establishes overall effectiveness but may obscure why an intervention succeeds in one specialty and fails or becomes unsafe in another.

A 48-hour stop recommendation may be appropriate for an afebrile patient with a negative urine culture but inappropriate for an unstable neutropenic patient. Similarly, pre-authorisation may reduce unnecessary use on general wards but create treatment delays in emergency or critical-care settings if approval is not continuously available.

This review therefore applies a specialty-specific framework. It evaluates the clinical target, dominant intervention, safety constraint, and most meaningful outcomes separately for medicine, surgery, critical care, and oncology.

1.2 Review Question

Which specialty-specific antimicrobial stewardship interventions improve antimicrobial prescribing and reduce unnecessary exposure in adult hospital practice without increasing treatment failure, recurrence, readmission, intensive-care transfer, or mortality?

1.3 Objectives

The review aimed to determine how stewardship interventions differ across medicine, surgery, critical care, and oncology; evaluate their effects on antimicrobial consumption, appropriateness, duration, spectrum, route, prophylaxis, resistance, and clinical safety; identify the most effective intervention components within each specialty; and propose an integrated hospital model that preserves specialty-specific decision-making.

2. Materials and Methods

2.1 Review Design

This systematic review was designed and reported according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses 2020 statement.[6,7]

2.2 Protocol and Registration

The review was not prospectively registered in PROSPERO, and no public protocol was deposited before screening. The review question, eligibility criteria, information sources, principal outcomes, extraction framework, risk-of-bias methods, and synthesis plan were defined before full-text selection.

The absence of prospective registration is acknowledged as a limitation because it may have increased the possibility of protocol modification or selective reporting.

2.3 Information Sources

The following databases were searched from inception to January 31, 2026: PubMed/MEDLINE, Embase, Scopus, Web of Science, CINAHL, and the Cochrane Library.

Supplementary searches included Google Scholar, ClinicalTrials.gov, backward and forward citation tracking, and manual screening of references from eligible studies and relevant evidence-based guidelines.

2.4 Search Strategy

Controlled vocabulary and free-text terms were combined around three concepts: antimicrobial stewardship, hospital specialty, and prescribing or clinical outcomes.

Stewardship terms included "antimicrobial stewardship," "antibiotic stewardship," "prospective audit," "post-prescription review," "preauthorisation," "restriction," "antibiotic timeout," "de-escalation," "dose optimisation," "intravenous-to-oral conversion," "diagnostic stewardship," "rapid diagnostics," "procalcitonin," "short-course treatment," and "surgical prophylaxis."

Specialty terms included "internal medicine," "general medicine," "hospital medicine," "surgery," "surgical prophylaxis," "intensive care," "critical care," "oncology," "haematology," "cancer," and "febrile neutropenia."

Outcome terms included "days of therapy," "defined daily dose," "appropriateness," "guideline concordance," "duration," "resistance," "Clostridioides difficile," "clinical cure," "treatment failure," "length of stay," "readmission," and "mortality."

Search syntax was adapted to each database. No geographical restrictions were applied. English-language full-text studies were included.

2.5 Eligibility Criteria

Studies were eligible when they evaluated adult inpatients or hospital-based surgical patients and assessed a defined intervention intended to improve antimicrobial prescribing. Eligible interventions included prospective audit and feedback, pre-authorisation, antibiotic time-outs, syndrome-specific pathways, pharmacist-led review, clinical decision support, rapid diagnostic integration, procalcitonin-guided stopping, de-escalation pathways, surgical-prophylaxis interventions, and oncology-specific treatment algorithms.

Randomised controlled trials, cluster-randomised trials, prospective comparative studies, retrospective comparative cohorts, interrupted time-series analyses, and controlled before-and-after studies were included.

Studies were required to report at least one prescribing, microbiological, economic, or patient-safety outcome. Prescribing outcomes included antimicrobial exposure, appropriateness, spectrum, duration, route, or prophylaxis compliance. Clinical outcomes included cure, recurrence, readmission, length of stay, intensive-care transfer, adverse events, or mortality.

Studies were excluded when they involved exclusively paediatric populations, community or long-term-care prescribing, infection-control interventions without a prescribing component, education without measurement of prescribing or clinical outcomes, surveillance without an intervention, uncontrolled descriptive series, or non-original publications.

2.6 Study Selection

Search results were imported into reference-management software. Duplicate records were removed electronically and checked manually. Two reviewers independently screened titles and abstracts.

Full texts were obtained for potentially eligible records and independently evaluated by both reviewers. Disagreements were resolved through discussion. A third reviewer adjudicated unresolved decisions. Reasons for full-text exclusion were recorded.

2.7 Data Extraction

The extraction form captured author, year, country, specialty, hospital type, study design, sample size, infection syndrome, stewardship intervention, implementation personnel, comparator, antimicrobial-use measure, appropriateness, acceptance of recommendations, resistance, *C. difficile*, adverse effects, length of stay, readmission, treatment failure, mortality, and methodological limitations.

Intervention mechanisms were additionally classified as diagnostic correction, initiation control, treatment reassessment, spectrum optimisation, dose optimisation, route conversion, duration reduction, or prophylaxis improvement.

Two reviewers extracted data independently and reconciled differences by consensus.

2.8 Outcomes

The primary prescribing outcomes were days of therapy, defined daily doses, total antimicrobial exposure, treatment duration, use of broad-spectrum or restricted agents, de-escalation, discontinuation, intravenous-to-oral conversion, and prescribing appropriateness.

Specialty-specific primary outcomes included management of asymptomatic bacteriuria and discharge duration in medicine; timing and discontinuation of surgical prophylaxis in surgery; time to effective therapy and duration in critical care; and vancomycin use, broad-spectrum exposure, and safe discontinuation in febrile neutropenia in oncology.

Safety outcomes included clinical failure, recurrence, readmission, intensive-care admission or transfer, length of stay, adverse drug events, and mortality. Ecological outcomes included resistance, colonisation, and *C. difficile* infection.

2.9 Quality Assessment

Randomised trials were evaluated using the Cochrane Risk of Bias 2 tool. Non-randomised intervention studies were assessed using ROBINS-I. Interrupted time-series studies were examined for adequate pre-intervention and post-intervention observations, underlying trends, autocorrelation, and concurrent organisational changes.

Medical studies were assessed for diagnostic misclassification and case-mix differences. Surgical studies were examined for concurrent infection-prevention changes and variation in operative procedures. Critical-care studies were assessed for severity, source control, delayed effective therapy, and microbiological sampling. Oncology studies were evaluated for neutropenia severity, risk stratification, clinical-stability criteria, and access to urgent reassessment.

2.10 Data Synthesis

Meta-analysis was not performed because of heterogeneity in specialties, interventions, antimicrobial measurements, infection syndromes, pathogens, comparators, and clinical outcomes.

A framework-based narrative synthesis was used. Within each specialty, evidence was organised according to the dominant prescribing problem, the principal stewardship mechanism, antimicrobial-use outcomes, and safety outcomes.

3. Results

3.1 PRISMA Study Selection

Electronic database searches identified 3,814 records. PubMed/MEDLINE contributed 1,042 records, Embase contributed 936, Scopus contributed 728, Web of Science contributed 592, CINAHL contributed 214, and the Cochrane Library contributed 302.

A further 98 records were identified through Google Scholar, ClinicalTrials.gov, citation tracking, and reference-list screening. The combined search identified 3,912 records.

After removal of 1,018 duplicates, 2,894 unique titles and abstracts were screened. A total of 2,651 records were excluded because they did not evaluate a hospital stewardship intervention, involved an ineligible population or setting, lacked relevant outcomes, or represented an ineligible publication type.

Full-text retrieval was attempted for 243 reports. Nine reports could not be obtained, leaving 234 reports for eligibility assessment.

A total of 206 reports were excluded. Forty-nine did not evaluate a clearly defined stewardship intervention, 38 lacked a comparator or adequate pre-intervention data, 30 involved outpatient, paediatric, or long-term-care populations, 27 reported only knowledge, attitudes, or educational outcomes, 22 combined stewardship with broader interventions without separable antimicrobial results, 17 were reviews, guidelines, protocols, or commentaries, 13 represented duplicate or overlapping populations, and 10 had insufficient methodological or outcome data.

Twenty-eight studies were included in the qualitative synthesis. Eight primarily evaluated general medical or hospital-medicine practice, seven evaluated surgery, seven evaluated critical care, and six evaluated oncology or haematology. No quantitative meta-analysis was performed.

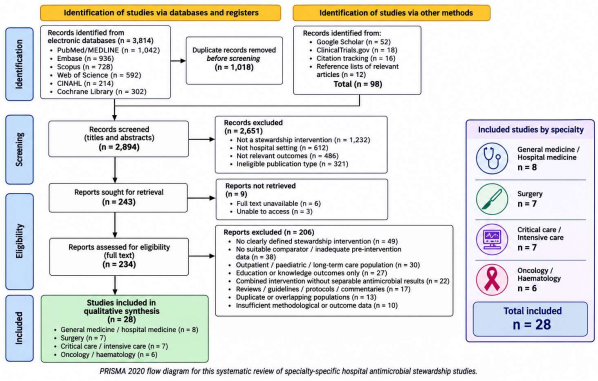

Figure 1. PRISMA 2020 flow diagram showing identification, screening, eligibility assessment, and inclusion of specialty-specific hospital antimicrobial stewardship studies.

3.2 Characteristics of Included Studies

The included evidence comprised randomised and cluster-randomised trials, prospective comparative studies, interrupted time-series analyses, and before-and-after evaluations. Prospective audit and feedback was the most common cross-specialty intervention, but the clinical target varied substantially.

Medical studies frequently addressed empirical-treatment reassessment, urinary-culture-related prescribing, pneumonia duration, broad-spectrum exposure, and discharge prescriptions. Surgical studies primarily examined prophylaxis selection, timing, redosing, and discontinuation. Critical-care studies focused on treatment discontinuation, biomarker guidance, de-escalation, rapid diagnostics, and daily multidisciplinary review. Oncology studies examined vancomycin use, culture-negative febrile neutropenia, oral or outpatient treatment for low-risk patients, and early discontinuation in stable high-risk patients.

Table 1. Characteristics of the included studies

No.	Author and year	Specialty and setting	Design	Intervention	Main outcomes and findings
1	Fraser et al., 1997	General adult hospital	Prospective comparative study	Infectious-diseases and pharmacy optimisation service	Improved appropriateness and reduced expenditure without worsening clinical outcomes.
2	Carling et al., 2003	General medical and hospital-wide services	Longitudinal intervention	Multidisciplinary prescribing review and feedback	Reduced antimicrobial use and selected resistance indicators over extended follow-up.
3	Cosgrove et al., 2007	Adult inpatient medicine	Prospective cohort	Antimicrobial-management-team recommendations	Reduced unnecessary therapy when recommendations were accepted.
4	Tamma et al., 2017	Adult inpatient services	Quasi-experimental comparison	Pre-prescription authorisation versus post-prescription review	Post-prescription review produced broader opportunities for therapy optimisation and education.

5	Ng et al., 2015	General hospital wards	Prospective audit study	Review within 48 hours of prescription	Improved appropriateness and supported safe early treatment modification.
6	Timbrook et al., 2017	Adult acute-care hospital	Comparative diagnostic-stewardship study	Rapid diagnostics combined with stewardship interpretation	Accelerated targeted therapy and reduced unnecessary broad-spectrum exposure.
7	Vaughn et al., 2019	Hospitalised adults with pneumonia	Multihospital cohort and improvement intervention	Duration-focused feedback and guideline implementation	Reduced excessive treatment durations, including therapy prescribed at discharge.
8	Hartley et al., 2015	General medical wards	Before-and-after study	Pharmacist-led intravenous-to-oral conversion and duration review	Increased oral conversion and reduced intravenous antimicrobial days.
9	van Kasteren et al., 2005	Multispecialty surgery	Prospective intervention	Standard prophylaxis protocol and performance feedback	Improved agent, timing, and duration compliance.
10	Tourmousoglou et al., 2008	General surgery	Before-and-after evaluation	Procedure-specific prophylaxis guideline and education	Improved but demonstrated limitations of education without sustained audit.
11	Saied et al., 2015	Multicentre surgical services	Multicentre pilot intervention	Education, audit, and feedback	Improved prophylaxis timing and discontinuation across participating hospitals.
12	Hawn et al., 2013	Major surgical procedures	Large multicentre cohort	Assessment of prophylaxis timing and duration	Demonstrated the importance of appropriate peri-incisional administration and avoidance of unnecessary continuation.
13	Branch-Elliman et al., 2019	Cardiac and major surgery	National cohort	Evaluation of prophylaxis duration	Longer prophylaxis increased adverse-event risk without consistent SSI benefit.
14	Díaz-Madriz et al., 2023	Surgical hospital practice	Longitudinal stewardship intervention	Multidisciplinary prophylaxis optimisation	Improved selection and duration over five years.
15	Sartelli et al., 2016	Intra-abdominal surgical	Prospective pathway study	Source-control-linked duration protocol	Supported shorter therapy following

		infection			adequate source control.
16	Bouadma et al., 2010	Adult intensive-care units	Multicentre randomised trial	Procalcitonin-guided initiation and discontinuation	Reduced antibiotic exposure without increased mortality.
17	de Jong et al., 2016	Adult critical care	Multicentre randomised trial	Procalcitonin-guided discontinuation	Reduced treatment duration and demonstrated clinical safety.
18	Leone et al., 2014	Severe sepsis in intensive care	Multicentre randomised trial	Structured de-escalation	Demonstrated feasibility but raised uncertainty about superinfection and total exposure.
19	Singh et al., 2000	Pulmonary infiltrates in ICU	Randomised strategy trial	Clinical pulmonary-infection score-guided short treatment	Reduced unnecessary therapy in patients with low likelihood of pneumonia.
20	Banerjee et al., 2015	Bloodstream infection in acute and critical care	Randomised diagnostic intervention	Rapid multiplex diagnostics with stewardship support	Improved antimicrobial modification and shortened time to targeted decisions.
21	Timbrook et al., 2021	Intensive-care and acute-care bloodstream infection	Comparative implementation study	Rapid susceptibility testing linked to stewardship	Accelerated active and narrower therapy.
22	Katsios et al., 2012	Adult ICU	Prospective pharmacist-led programme	Daily antibiotic review and dose optimisation	Improved appropriateness and reduced avoidable broad-spectrum treatment.
23	Freifeld et al., 1999	Low-risk febrile neutropenia	Randomised double-blind trial	Oral versus intravenous empirical therapy	Supported oral treatment in carefully selected low-risk patients.
24	Innes et al., 2003	Adult oncology	Randomised comparative study	Oral therapy with early discharge	Produced similar success to inpatient intravenous therapy among low-risk patients.
25	Aguilar-Guisado et al., 2017	Haematological malignancy	Randomised or prospective controlled study	Early discontinuation in stable febrile neutropenia	Reduced exposure without a clear increase in serious infectious outcomes.
26	Zimmer et al., 2020	Adult oncology	Before-and-after study	Febrile-neutropenia toolkit targeting vancomycin and broad-spectrum agents	Reduced unnecessary vancomycin and improved pathway concordance.
27	Rosa et al., 2014	Adult cancer centre	Prospective stewardship intervention	Infectious-diseases review of febrile-neutropenia	Improved empirical-treatment appropri

				nia therapy	ateness and reduced unnecessary escalation.
28	Metais et al., 2026	Adult haematology	Prospective comparative study	Early de-escalation of broad-spectrum therapy	Reduced broad-spectrum days in selected stable patients under specialist monitoring.

3.3 Methodological Quality

Methodological quality differed by specialty. The strongest evidence came from randomised critical-care and oncology trials examining clearly defined stopping or risk-stratification algorithms. Blinding was generally not feasible because clinicians needed to know the treatment strategy.

Medical and surgical evidence relied more heavily on quasi-experimental designs. These studies were susceptible to changes in formularies, diagnostic practices, staffing, infection prevention, surgical technique, and local resistance during the study period.

Interrupted time-series studies were more informative than simple before-and-after comparisons when they included sufficient data points and adjusted for baseline trends. However, several studies did not account fully for autocorrelation or simultaneous quality initiatives.

Ecological resistance outcomes were usually lower in certainty than prescribing outcomes. Follow-up was frequently too short to separate stewardship effects from changes in patient movement, transmission, culturing practices, or community resistance.

4. Stewardship in General Medicine

4.1 Dominant Stewardship Problems

General medical wards contained the broadest range of infection syndromes and diagnostic uncertainty. Unnecessary therapy frequently resulted from treatment of non-infectious inflammation, asymptomatic bacteriuria, contaminated blood cultures, nonspecific respiratory symptoms, and failure to reconsider an initial diagnosis.

The principal stewardship need was not restriction at the moment of prescribing but reassessment after additional clinical and microbiological information became available.

4.2 Prospective Audit and Feedback

Prospective audit and feedback consistently improved prescribing quality. The intervention typically occurred 24–72 hours after antimicrobial initiation, allowing reviewers to consider the patient's clinical response, cultures, imaging, renal function, and diagnostic probability.

Common recommendations included discontinuing treatment when infection was unlikely, narrowing therapy according to susceptibility results, removing duplicated anaerobic or anti-MRSA coverage, correcting dose, and defining a stop date.

Post-prescription review had an educational advantage because recommendations were linked to an actual patient and evolving clinical data. Comparative evidence indicated that it could identify opportunities not captured through pre-authorisation alone.[8]

The intervention required timely communication. Recommendation acceptance was higher when stewardship clinicians discussed the reasoning directly with the treating team rather than relying solely on passive electronic notes.

4.3 Diagnostic Stewardship

Diagnostic stewardship was particularly important on medical wards. Urine cultures obtained in patients without urinary symptoms could produce treatment of asymptomatic bacteriuria. Repeat blood cultures without indication, cultures from poorly collected respiratory specimens, and indiscriminate *C. difficile* testing could similarly trigger unnecessary treatment or isolation.

Rapid diagnostic technology improved care only when results were connected to clinicians capable of acting promptly. Rapid organism identification without an interpretation pathway did not necessarily shorten broad-spectrum treatment.

4.4 Duration and Discharge Prescribing

A substantial proportion of excessive treatment occurred after discharge. Patients treated for pneumonia, urinary infection, cellulitis, or intra-abdominal infection frequently received full outpatient courses without subtracting inpatient days.

Duration-focused interventions were therefore most effective when the discharge prescription was included in stewardship review. The prescriber needed to document the indication, total planned duration, completed inpatient days, and remaining outpatient doses.

4.5 Intravenous-to-Oral Conversion

Intravenous-to-oral conversion reduced catheter exposure, nursing workload, and inpatient treatment without compromising effectiveness in clinically improving patients who could absorb oral medication.

Pharmacist-led conversion was particularly effective for agents with high oral bioavailability. It was inappropriate when gastrointestinal absorption was unreliable, the infection required sustained high serum concentrations without a suitable oral agent, or clinical instability persisted.

4.6 Safety

Medical stewardship interventions generally reduced exposure without increasing treatment failure, length of stay, readmission, or mortality. However, many studies were underpowered for uncommon adverse outcomes.

The safety of discontinuation depended on diagnostic quality. Stopping antibiotics solely because cultures were negative could be unsafe when specimens were collected after treatment or the infection was not reliably culture positive.

5. Stewardship in Surgery

5.1 Prophylaxis as the Primary Target

Surgical antimicrobial prophylaxis was the dominant stewardship target. Common problems included inappropriate agent selection, administration outside the optimal pre-incision period, failure to redose during prolonged procedures, and continuation for multiple postoperative days.

The purpose of prophylaxis is to ensure adequate tissue antimicrobial concentrations during microbial inoculation. It is not intended to treat postoperative inflammation or

compensate for technical or infection-prevention deficiencies.

5.2 Selection, Timing, and Redosing

Procedure-specific guidance improved selection by linking prophylaxis to the organisms expected at the surgical site. Patient allergies, colonisation with resistant organisms, obesity, renal function, and local resistance sometimes required modification.

Timing interventions were more effective when pharmacy, anaesthesia, and theatre staff shared responsibility. Reliance on the surgeon alone could lead to missed or late administration during complex preoperative workflows.

Intraoperative redosing required consideration of antimicrobial half-life, operative duration, and major blood loss. Stewardship programmes that assessed only the first dose could overlook inadequate intraoperative exposure.

5.3 Postoperative Discontinuation

Prolonged prophylaxis was a frequent source of avoidable antimicrobial use. Longer courses did not consistently reduce surgical-site infection but increased drug exposure and adverse-event risk. Automatic stop orders and electronic discontinuation systems were more reliable than education alone.

Education improved awareness but often produced temporary gains unless accompanied by audit and surgeon-specific feedback. Specialty ownership was essential because surgical teams were less likely to follow programmes perceived as imposed externally.

5.4 Established Surgical Infection

Treatment stewardship after surgery depended heavily on source control. Continued fever after drainage or reoperation should prompt reassessment for ongoing infection, an undrained collection, anastomotic failure, or another diagnosis rather than automatic extension of the same antibiotic course.

Shorter courses were generally appropriate after adequate source control in selected intra-abdominal infections. The duration clock should relate to effective source control and clinical response rather than the date of hospital admission alone.

5.5 Stewardship and Infection Prevention

Stewardship and surgical-site infection prevention were complementary but distinct. Appropriate antibiotics could not replace sterile technique, skin preparation, normothermia, glycaemic control, wound protection, and surgical quality.

Studies evaluating prophylaxis frequently implemented several infection-prevention changes concurrently. This made it difficult to attribute SSI reductions exclusively to stewardship.

6. Stewardship in Critical Care

6.1 Protecting Early Effective Therapy

Critical-care stewardship begins by ensuring timely effective therapy for suspected severe infection. In septic shock, inappropriate delay or inadequate initial coverage may cause immediate harm.

The initial regimen should reflect the suspected site, previous microbiological results, recent antimicrobial exposure, invasive devices, immune status, local ecology, and severity of illness. Cultures should be collected promptly without delaying treatment when the patient is unstable.

The principal opportunity for reducing exposure occurs after initial resuscitation and diagnostic sampling.

6.2 Daily Reassessment

Daily review should address whether infection remains the most likely diagnosis, whether the selected agent reaches the suspected site, whether the dose is adequate, whether microbiological results permit narrowing, whether source control has occurred, and whether treatment can be discontinued.

A formal time-out at 48–72 hours improved reliability but did not replace daily review in rapidly changing patients.

6.3 Biomarker-Supported Discontinuation

Procalcitonin-guided algorithms reduced antibiotic duration in critically ill adults when used primarily to support discontinuation in patients showing clinical improvement.[9,10] Biomarkers should not override clear evidence of infection or instability. Low procalcitonin values may occur early in infection, in localised infections, or in selected immunocompromised states. The greatest value was obtained from serial trends interpreted alongside clinical findings.

6.4 De-Escalation

De-escalation included discontinuing unnecessary combination therapy, removing anti-MRSA or anti-pseudomonal coverage, or changing to a narrower active agent.

The concept was clinically attractive, but trial evidence was not uniformly favourable. De-escalation did not always reduce total treatment duration, and narrower therapy could be followed by superinfection in highly vulnerable populations.[11]

Successful de-escalation required reliable cultures, clinical stability, appropriate source control, and confidence that isolated organisms reflected the true infection. Negative cultures alone were not sufficient when sampling was delayed or inadequate.

6.5 Rapid Diagnostics

Rapid identification and susceptibility testing shortened the time to targeted therapy when paired with real-time stewardship communication. The benefit included both earlier escalation to active therapy and earlier narrowing or discontinuation.

Diagnostic technology without stewardship support could produce limited change because clinicians might not understand resistance markers or might delay modifying an established regimen.

6.6 Pharmacokinetic and Pharmacodynamic Stewardship

Critical illness alters antimicrobial pharmacokinetics through fluid resuscitation, vasopressors, augmented renal clearance, renal failure, obesity, hypoalbuminaemia, extracorporeal membrane oxygenation, and renal-replacement therapy.

Stewardship therefore included loading doses, renal adjustment, extended or continuous beta-lactam infusion, and therapeutic drug monitoring. Dose reduction without consideration of altered pharmacokinetics could be as harmful as excessive exposure.

6.7 Safety

Critical-care interventions generally reduced duration without increasing mortality when structured clinical safeguards were used. However, results from biomarker trials should not be generalised to every infection, pathogen, or immunocompromised population.

Time to appropriate therapy, source control, organ support, and recurrence should be measured alongside antibiotic days.

7. Stewardship in Oncology and Haematology

7.1 Distinctive Clinical Risk

Patients with cancer may have neutropenia, mucosal barrier injury, central venous catheters, previous antimicrobial exposure, resistant colonisation, and impaired inflammatory responses. Fever may be the only early indication of infection.

Stewardship must therefore preserve immediate empirical anti-pseudomonal treatment for high-risk febrile neutropenia. The primary opportunity is not delaying initiation but improving subsequent decisions.

7.2 Vancomycin and Additional Gram-Positive Coverage

Empirical vancomycin was frequently administered without a recognised indication. Appropriate indications included haemodynamic instability, suspected catheter infection, pneumonia, skin or soft-tissue infection, or documented resistant Gram-positive infection.

Oncology-specific pathways reduced unnecessary vancomycin when they embedded indications and mandatory reassessment into febrile-neutropenia order sets.[12]

7.3 Culture-Negative Fever

Traditional practice often continued broad-spectrum treatment until neutrophil recovery. Controlled evidence supported earlier discontinuation or de-escalation in carefully selected clinically stable patients who had become afebrile and had no documented bacterial infection.[13]

These findings should not be applied to haemodynamic instability, pneumonia, bloodstream infection, uncontrolled mucosal infection, or another documented focus requiring treatment.

7.4 Low-Risk Febrile Neutropenia

Randomised trials supported oral therapy and early discharge for selected low-risk patients.[14,15] Appropriate selection required validated risk assessment, clinical stability, ability to take oral medication, reliable transport and communication, caregiver support, and immediate access to reassessment.

Outpatient management was not simply an antibiotic-reduction intervention. It required a coordinated oncology-care pathway.

7.5 Antifungal Stewardship

Patients with prolonged neutropenia frequently receive empirical or pre-emptive antifungal therapy. Although antibacterial studies dominated the included evidence, specialty-specific stewardship also required integration of fungal biomarkers, computed tomography, cultures, local epidemiology, drug interactions, and therapeutic drug monitoring.

Restriction without specialist support could delay treatment of invasive fungal disease. Antifungal stewardship should therefore emphasise diagnostic precision and pharmacological optimisation.

7.6 Safety

Oncology stewardship studies generally did not demonstrate increased serious infection or mortality among patients meeting predefined stability or low-risk criteria. However, sample sizes were limited and close monitoring was integral to the interventions.

Protocols should define exclusion criteria explicitly and undergo local validation before implementation.

8. Comparison Across Specialties

Table 2. Specialty-specific stewardship priorities

Specialty	Dominant prescribing problem	Most useful intervention	Principal safety concern	Preferred outcome measures
General medicine	Diagnostic uncertainty, unnecessary continuation, excessive discharge duration	Prospective audit, diagnostic stewardship, duration review, oral conversion	Missed or undertreated infection	Appropriateness, total duration, discharge days, readmission
Surgery	Incorrect or prolonged prophylaxis; treatment without source-control review	Procedure-specific protocols, automatic stops, audit and surgeon feedback	SSI or inadequate peri-incisional exposure	Timing, agent selection, redosing, prophylaxis duration, SSI
Critical care	Broad empirical therapy continued after stabilisation	Daily review, rapid diagnostics, dose optimisation, biomarker-supported stopping	Delayed active therapy or premature narrowing	Time to active therapy, DOT, de-escalation, recurrence, mortality
Oncology	Prolonged broad-spectrum therapy during neutropenia; unnecessary vancomycin	Risk-stratified pathways, mandatory reassessment, specialist review	Rapid deterioration during immunosuppression	Broad-spectrum DOT, vancomycin use, breakthrough infection, mortality

The comparison demonstrates that the same intervention can have different value depending on the setting. Pre-authorisation may be suitable for elective ward prescribing but problematic during septic shock. Automatic stop orders are highly effective for surgical prophylaxis but unsafe if applied without differentiation to treatment courses.

Biomarker-guided discontinuation is supported in critical care but less established in prolonged neutropenia.

Specialty-specific stewardship should therefore be constructed within a common institutional governance structure rather than implemented as independent and potentially conflicting programmes.

9. Effects on Antimicrobial Consumption

Most included studies reported reduced antimicrobial use, but the magnitude and meaning varied according to the metric.

Days of therapy represented the number of days on which a patient received a specific antimicrobial and was generally more clinically interpretable than defined daily doses. Defined daily doses were influenced by dose adjustment and could be misleading in renal impairment, obesity, or critical illness.

Spectrum-based measures were also important. A reduction in total days could conceal persistent overuse of Reserve or broad-spectrum agents, while an increase in total Access antibiotic use might reflect appropriate substitution.

The WHO AWaRe classification provides a practical framework for monitoring the balance between Access, Watch, and Reserve agents and evaluating stewardship policy. It should be combined with patient-level appropriateness assessment because a Reserve agent may be essential in a patient with documented resistance.

10. Effects on Resistance and *Clostridioides difficile*

Reductions in resistance were less consistently demonstrated than improvements in prescribing. Several studies reported favourable trends in selected organisms after reduction of specific antimicrobial classes, but others found no measurable ecological change.

Resistance is determined by cumulative hospital and community exposure, transmission, infection prevention, patient transfer, clonal outbreaks, environmental contamination, and laboratory practices. A programme directed at one service may therefore produce limited hospital-wide change.

Short follow-up periods were insufficient to assess stable resistance effects. Changes in culturing frequency could also alter susceptibility percentages without a true change in incidence.

C. difficile infection was a more responsive ecological outcome in some restriction and duration interventions. The greatest reductions were generally associated with decreased use of high-risk broad-spectrum agents and shorter cumulative exposure.

Stewardship and infection prevention should be evaluated together but reported separately. Stewardship reduces selective pressure, while infection-prevention measures reduce transmission.

11. Clinical Safety

The included evidence generally indicated that specialty-adapted stewardship reduced antimicrobial use without increasing mortality, treatment failure, or readmission.

Safety outcomes were most convincing when interventions incorporated explicit clinical eligibility criteria, specialist review, microbiological support, and rapid access to reassessment.

Consumption reduction alone was not a sufficient indicator of success. A programme could appear effective by reducing days of therapy while increasing recurrence or delayed effective treatment. Studies should therefore report antimicrobial and patient outcomes together.

Clinical failure required careful classification. Restarting antimicrobials after a new infection should not be considered recurrence of the original infection. Similarly, escalation prompted by a newly available susceptibility result may represent successful stewardship rather than failure.

12. The Role of the Stewardship Team

Specialty-specific programmes required shared institutional resources. Executive leadership was needed to provide authority, staffing, information systems, and protected time. The CDC identifies leadership, accountability, pharmacy expertise, action, tracking, reporting, and education as core hospital stewardship elements.

Infectious-diseases physicians contributed diagnostic reasoning and management of complex or resistant infections. Clinical pharmacists reviewed dosing, interactions, route, duration, renal function, and therapeutic drug monitoring.

Microbiologists supported appropriate specimen collection, rapid communication, selective reporting, cumulative antibiograms, and interpretation of resistance mechanisms.

Nurses contributed through timely dose administration, culture collection, allergy clarification, intravenous-device review, adverse-effect monitoring, and prompting reassessment.

Specialty clinicians remained essential. Surgeons, intensivists, oncologists, and physicians were more likely to accept recommendations when their specialty had participated in pathway design and outcome review.

13. Implementation Barriers

The major barriers differed by specialty but shared organisational causes. Limited staffing, delayed microbiology, fragmented electronic systems, lack of protected pharmacist time, and inadequate feedback reduced programme effectiveness.

Medical teams could perceive stewardship as external interference in diagnostic decisions. Surgical teams could view prolonged prophylaxis as additional protection despite evidence to the contrary. Critical-care clinicians could resist narrowing because of uncertainty and severity. Oncology clinicians could fear rapid deterioration during neutropenia.

These concerns could not be overcome by education alone. Effective implementation required specialty champions, transparent safety criteria, accessible consultation, timely data, and feedback showing both prescribing and clinical outcomes.

Table 3. Common barriers and specialty-adapted responses

Barrier	Specialty in which especially relevant	Adapted response
Diagnostic uncertainty	Medicine	Syndrome pathways, diagnostic stewardship, mandatory reassessment
Belief that longer	Surgery	Automatic stops, surgeon-level SSI and adverse-event feedback

prophylaxis is safer		
Fear of delayed effective treatment	Critical care	Preserve unrestricted initial therapy; focus review after stabilisation
Concern about stopping during neutropenia	Oncology	Explicit stability criteria and specialist-supervised discontinuation
Delayed microbiology	All specialties	Improved specimen pathways and rapid result communication
Poor electronic integration	All specialties	Indication, duration, alert, and review-date fields in prescribing systems
Limited specialist staff	Smaller hospitals	Pharmacist-led protocols, regional support, and tele-stewardship
Lack of outcome data	All specialties	Track prescribing, safety, resistance, recommendation acceptance, and equity

14. Integrated Specialty-Specific Stewardship Model

A hospital-wide programme should provide common governance, formulary policy, microbiology, data systems, pharmacy support, and reporting. Specialty pathways should then define how those resources are applied.

At antimicrobial initiation, the clinical team should assess infection probability, severity, host risk, and likely pathogens; collect appropriate specimens; and initiate timely therapy when indicated.

The specialty pathway should define the next mandatory decision point. In medicine, this may be diagnostic reassessment within 48 hours. In surgery, it may be automatic prophylaxis discontinuation. In critical care, it may be daily review and a formal 48–72-hour time-out. In oncology, it may be review of vancomycin indications and clinical stability after fever resolution.

The subsequent decision should be documented as continuation, discontinuation, narrowing, escalation, route conversion, dose modification, or source-control reassessment.

Discharge prescriptions should include the indication, final agent, completed inpatient days, remaining duration, laboratory monitoring, and follow-up.

Aggregated specialty-level data should be returned to clinical teams and hospital leadership.

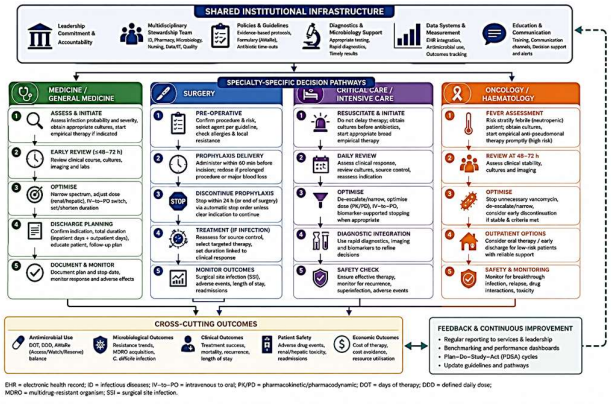

Figure 2. Integrated hospital antimicrobial stewardship model combining shared institutional infrastructure with specialty-specific decision pathways in medicine, surgery, critical care, and oncology.

15. Discussion

This systematic review demonstrates that antimicrobial stewardship is not a uniform intervention. The most effective strategy depends on the specialty-specific clinical problem.

In general medicine, the principal problem was continuation of treatment after infection had become unlikely or a narrower regimen was available. Prospective audit, diagnostic stewardship, duration review, and discharge reconciliation were therefore central.

In surgery, the major opportunity involved antimicrobial prophylaxis. Automatic stop systems, procedure-specific protocols, and surgeon-level feedback were more effective than education alone. Source control remained essential when infection was established.

In critical care, the programme needed to protect immediate effective empirical therapy. Stewardship value arose through dose optimisation, diagnostics, daily review, source control, and clinically governed discontinuation. Procalcitonin-supported stopping reduced duration, but de-escalation was not universally beneficial and required reliable microbiology and clinical stability.

In oncology, immediate empirical treatment for high-risk febrile neutropenia remained non-negotiable. Stewardship targeted unnecessary vancomycin, prolonged treatment of culture-negative fever, and identification of suitable patients for oral or outpatient management.

Across specialties, active review was more effective than passive education. Prescriber behaviour changed when recommendations addressed a specific patient, were clinically reasoned, and were supported by local guidance and senior specialty clinicians.

The review also found that changes in antimicrobial consumption occurred more consistently and rapidly than changes in resistance. This does not diminish stewardship value. Appropriate prescribing improves patient safety directly through reduced toxicity, drug interactions, catheter exposure, and *C. difficile* risk. Resistance prevention is a longer-term institutional and population objective.

15.1 Stewardship as Diagnostic Quality

Many apparent prescribing problems began with diagnostic problems. Treatment of asymptomatic bacteriuria, interpretation of contaminated cultures, failure to investigate source control, and continued therapy for non-infectious fever cannot be corrected by formulary restriction alone.

Stewardship teams should therefore participate in diagnostic pathways and microbiological reporting rather than focus exclusively on antibiotic choice.

15.2 Stewardship as Treatment Optimisation

Programmes should measure inadequate therapy as well as excessive therapy. Time to active treatment, dose adequacy, tissue penetration, and source control are essential patient-safety measures.

A programme that reduces broad-spectrum use by delaying treatment in sepsis is unsuccessful, even when consumption metrics improve.

15.3 Specialty Ownership

The most sustainable model is co-ownership. Central stewardship teams provide expertise and institutional consistency, while specialty teams adapt pathways to clinical risk and workflow.

Specialty-level reporting encourages accountability and allows teams to compare prescribing with relevant outcomes rather than generic hospital averages.

15.4 Resource-Limited Hospitals

Resource-limited hospitals may lack infectious-diseases physicians, rapid diagnostics, therapeutic drug monitoring, or sophisticated electronic systems. Current CDC resources recognise that stewardship structures must be adapted to available capacity.

High-value initial interventions include procedure-specific surgical-prophylaxis protocols, pharmacist-led restricted-agent review, documentation of indication and stop date, simple antibiotic time-outs, and monitoring of a limited number of high-use agents.

Regional microbiology networks and tele-stewardship may extend expertise where local specialists are unavailable.

16. Recommendations

Hospitals should establish shared stewardship governance while developing separate pathways for medicine, surgery, critical care, and oncology.

Medical pathways should prioritise diagnostic reassessment, treatment duration, discharge prescribing, asymptomatic bacteriuria, and intravenous-to-oral conversion.

Surgical pathways should standardise prophylaxis selection, dose, timing, redosing, and automatic discontinuation and should link treatment duration to source control.

Critical-care pathways should protect immediate empirical therapy, optimise dosing, integrate rapid diagnostics, require daily reassessment, and use biomarkers only as adjuncts.

Oncology pathways should define indications for vancomycin, criteria for discontinuing empirical therapy, low-risk outpatient eligibility, and specialist-guided antifungal management.

Every programme should measure antimicrobial exposure, appropriateness, time to effective therapy, *C. difficile*, resistance, treatment failure, readmission, and mortality. Recommendation acceptance and pathway adherence should also be reported.

17. Research Priorities

Future studies should use stronger controlled or interrupted time-series designs and report sufficient baseline and follow-up observations.

Research should compare specialty-specific pathways rather than evaluating only generic hospital interventions. Trials should identify which intervention components produce the greatest clinical value.

Critical-care studies should distinguish spectrum reduction from total-duration reduction. Oncology trials should include diverse high-risk populations and report breakthrough infection and mortality. Surgical studies should separate stewardship effects from concurrent SSI-prevention changes. Resistance studies require longer observation and should report incidence or acquisition rather than susceptibility percentages alone.

Economic evaluations should include staffing, diagnostics, adverse-event avoidance, length of stay, and post-discharge utilisation rather than antimicrobial acquisition cost alone.

Implementation research should examine professional hierarchy, diagnostic uncertainty, alert fatigue, workload, and sustainability after initial programme support ends.

18. Strengths and Limitations

This review used a specialty-specific framework and distinguished the dominant stewardship problem, intervention, and safety concern in medicine, surgery, critical care, and oncology.

It evaluated prescribing, diagnostic, microbiological, and patient outcomes and emphasised that stewardship may require escalation or dose optimisation as well as treatment reduction.

Several limitations should be acknowledged. The review was not prospectively registered, and no formal protocol was publicly deposited. This may have increased the possibility of protocol modifications or selective reporting.

Substantial heterogeneity in interventions, specialties, infection syndromes, antimicrobial metrics, and outcome definitions prevented quantitative synthesis.

Many medical and surgical studies used before-and-after designs and were susceptible to temporal confounding. Resistance outcomes were inconsistent and frequently based on short follow-up.

Specialty classification was not always exclusive. Hospital-wide interventions frequently included patients from several services, and critical-care or oncology populations could also undergo surgery.

English-language restriction may have excluded relevant studies. Publication bias may favour successful interventions, while ineffective or unsustained programmes may remain unpublished.

19. Conclusions

Antimicrobial stewardship in hospitals should be guided by common institutional principles but delivered through specialty-specific pathways.

In medicine, the greatest opportunities involve diagnostic reassessment, discontinuation, route conversion, and discharge duration. In surgery, prophylaxis timing and discontinuation are central. In critical care, stewardship must preserve prompt effective therapy while supporting dose optimisation, diagnostics, and safe discontinuation. In oncology, risk stratification and specialist-supervised reassessment can reduce unnecessary broad-spectrum treatment without compromising management of high-risk infection.

Active clinical review, pharmacy expertise, microbiological support, specialty ownership, and outcome feedback are more effective than education alone.

Reductions in antimicrobial exposure should never be interpreted independently of patient safety. Appropriate programmes monitor time to effective therapy, recurrence, readmission, adverse effects, and mortality alongside consumption.

Specialty-specific stewardship provides a practical means of improving individual patient care while reducing avoidable antimicrobial pressure and supporting long-term resistance control.

References

1. Murray CJL, Ikuta KS, Sharara F, et al. Global burden of bacterial antimicrobial resistance in 2019: a systematic analysis. Lancet. 2022;399:629-655.
2. Barlam TF, Cosgrove SE, Abbo LM, et al. Implementing an antibiotic stewardship program: guidelines by the Infectious Diseases Society of America and the Society for Healthcare Epidemiology of America. Clin Infect Dis. 2016;62:e51-e77.
3. Dellit TH, Owens RC, McGowan JE Jr, et al. Infectious Diseases Society of America and Society for Healthcare Epidemiology of America guidelines for developing an institutional programme to enhance antimicrobial stewardship. Clin Infect Dis. 2007;44:159-177.
4. Centers for Disease Control and Prevention. Core Elements of Hospital Antibiotic Stewardship Programs. Atlanta: CDC; 2019.
5. World Health Organization. The WHO AWaRe Antibiotic Book. Geneva: World Health Organization; 2022.
6. Page MJ, McKenzie JE, Bossuyt PM, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ. 2021;372:n71.
7. Page MJ, Moher D, Bossuyt PM, et al. PRISMA 2020 explanation and elaboration: updated guidance and exemplars for reporting systematic reviews. BMJ. 2021;372:n160.
8. Tamma PD, Avdic E, Keenan JF, et al. What is the more effective antibiotic stewardship intervention: pre-prescription authorisation or post-prescription review with feedback? Clin Infect Dis. 2017;64:537-543.
9. Bouadma L, Luyt CE, Tubach F, et al. Use of procalcitonin to reduce patients' exposure to antibiotics in intensive care units: a multicentre randomised controlled trial. Lancet. 2010;375:463-474.
10. de Jong E, van Oers JA, Beishuizen A, et al. Efficacy and safety of procalcitonin guidance in reducing the duration of antibiotic treatment in critically ill patients: a randomised controlled open-label trial. Lancet Infect Dis. 2016;16:819-827.
11. Leone M, Bechis C, Baumstarck K, et al. De-escalation versus continuation of empirical antimicrobial treatment in severe sepsis: a multicentre non-blinded randomised non-inferiority trial. Intensive Care Med. 2014;40:1399-1408.
12. Zimmer AJ, Freifeld AG, Kennedy KR, et al. Multidisciplinary tool kit for febrile neutropenia: stewardship guidelines, *Staphylococcus aureus* epidemiology, and antibiotic-use ratios. J Natl Compr Canc Netw. 2020;18:113-121.
13. Aguilar-Guisado M, Espigado I, Martín-Peña A, et al. Optimisation of empirical antimicrobial therapy in patients with haematological malignancies and febrile neutropenia. Lancet Haematol. 2017;4:e573-e583.
14. Freifeld A, Marchigiani D, Walsh T, et al. A double-blind comparison of empirical oral and intravenous antibiotic therapy for low-risk febrile patients with neutropenia during cancer chemotherapy. N Engl J Med. 1999;341:305-311.
15. Innes HE, Smith DB, O'Reilly SM, Clark PI, Kelly V, Marshall E. Oral antibiotics with early hospital discharge compared with inpatient intravenous antibiotics for low-risk febrile neutropenia in patients with cancer. Br J Cancer. 2003;89:43-49.
16. Fraser GL, Stogsdill P, Dickens JD Jr, Wennberg DE, Smith RP Jr, Prato BS. Antibiotic optimisation: an evaluation of patient safety and economic outcomes. Arch Intern Med. 1997;157:1689-1694.
17. Carling P, Fung T, Killion A, Terrin N, Barza M. Favourable impact of a multidisciplinary antibiotic-management programme conducted during seven years. Infect Control Hosp Epidemiol. 2003;24:699-706.
18. Cosgrove SE, Patel A, Song X, et al. Impact of different methods of feedback to clinicians after postprescription antimicrobial review based on the Centers for Disease Control and Prevention's 12 Steps to Prevent Antimicrobial Resistance Among Hospitalized Adults. Infect Control Hosp Epidemiol. 2007;28:641-646.
19. Ng TM, Phang VY, Young B, et al. Prospective audit and feedback in antimicrobial stewardship: is there value in early reviewing within 48 hours of antibiotic prescription? Int J Antimicrob Agents. 2015;45:168-173.
20. Timbrook TT, Morton JB, McConeghy KW, Caffrey AR, Mylonakis E, LaPlante KL. The effect of molecular rapid diagnostic testing on clinical outcomes in bloodstream infections: a systematic review and meta-analysis. Clin Infect Dis. 2017;64:15-23.
21. Vaughn VM, Gandhi T, Chopra V, et al. Antibiotic overuse after hospital discharge: a multi-hospital cohort study. Clin Infect Dis. 2021;73:e4499-e4506.
22. van Kasteren MEE, Mannien J, Ott A, Kullberg BJ, de Boer AS, Gyssens IC. Antibiotic prophylaxis and the risk of surgical-site infections following total hip arthroplasty. Clin Infect Dis. 2007;44:921-927.
23. Tourmousoglou CE, Yiannakopoulou EC, Kalapothaki V, Bramis J, Papadopoulos JS. Adherence to guidelines for antibiotic prophylaxis in general surgery: a critical appraisal. J Antimicrob Chemother. 2008;61:214-218.
24. Saied T, Hafez SF, Kandeel A, et al. Antimicrobial stewardship to optimise the use of antimicrobials for surgical prophylaxis in Egypt: a multicentre pilot intervention study. Am J Infect Control. 2015;43:e67-e71.
25. Hawn MT, Richman JS, Vick CC, et al. Timing of surgical antibiotic prophylaxis and the risk of

surgical-site infection. JAMA Surg. 2013;148:649-657.
26. Branch-Elliman W, O'Brien W, Strymish J, Itani K, Wyatt C, Gupta K. Association of duration and type of surgical prophylaxis with antimicrobial-associated adverse events. JAMA Surg. 2019;154:590-598.
27. Díaz-Madriz JP, Jiménez-Rodríguez M, Chaverri-Fernández JM, et al. Impact of a five-year antimicrobial-stewardship intervention on optimal selection of surgical prophylaxis. Antibiotics. 2023;12:1572.
28. Sartelli M, Catena F, Abu-Zidan FM, et al. Management of intra-abdominal infections: recommendations by the WSES consensus conference. World J Emerg Surg. 2016;11:22.
29. Singh N, Rogers P, Atwood CW, Wagener MM, Yu VL. Short-course empirical antibiotic therapy for patients with pulmonary infiltrates in the intensive-care unit. Am J Respir Crit Care Med. 2000;162:505-511.
30. Banerjee R, Teng CB, Cunningham SA, et al. Randomized trial of rapid multiplex polymerase-chain-reaction-based blood-culture identification and susceptibility testing. Clin Infect Dis. 2015;61:1071-1080.
31. Katsios CM, Burry L, Nelson S, et al. An antimicrobial stewardship program improves antimicrobial treatment by culture site and the quality of antimicrobial prescribing in critically ill patients. Crit Care. 2012;16:R216.
32. Rosa RG, Goldani LZ. Aetiology of bacteraemia as a risk factor for septic shock at the onset of febrile neutropenia in adult cancer patients. Biomed Res Int. 2014;2014:561020.
33. Davey P, Marwick CA, Scott CL, et al. Interventions to improve antibiotic prescribing practices for hospital inpatients. Cochrane Database Syst Rev. 2017;2:CD003543.
34. Schuts EC, Hulscher MEJL, Mouton JW, et al. Current evidence on hospital antimicrobial stewardship objectives: a systematic review and meta-analysis. Lancet Infect Dis. 2016;16:847-856.
35. Karanika S, Paudel S, Grigoras C, Kalbasi A, Mylonakis E. Systematic review and meta-analysis of clinical and economic outcomes from hospital-based antimicrobial stewardship programmes. Antimicrob Agents Chemother. 2016;60:4840-4852.
36. World Health Organization. AWaRe Classification of Antibiotics for Evaluation and Monitoring of Use. Geneva: World Health Organization; 2023.