



Framework of Antimicrobial Resistance in the ICU: Risk Factors, Pathogenesis, Prevention, and Clinical Pharmacist Interventions

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ABSTRACT:

Antimicrobial resistance (AMR) is a major global public health problem and is particularly challenging in the Intensive Care Unit (ICU), where critically ill patients are highly susceptible to severe infections. The frequent use of broad-spectrum antibiotics, invasive medical devices, prolonged hospital stays, and immunocompromised conditions contribute to the emergence and spread of multidrug-resistant (MDR) pathogens. Common resistant organisms in ICUs include methicillin-resistant *Staphylococcus aureus* (MRSA), vancomycin-resistant *Enterococcus* (VRE), extended-spectrum β -lactamase (ESBL)-producing Enterobacterales, carbapenem-resistant Enterobacterales (CRE), multidrug-resistant *Pseudomonas aeruginosa*, and *Acinetobacter baumannii*. AMR leads to treatment failure, prolonged ICU stay, increased healthcare costs, higher mortality, and limited therapeutic options. Effective management requires antimicrobial stewardship, infection prevention and control measures, rapid diagnostic techniques, and optimization of antimicrobial therapy. Clinical pharmacists play a vital role in promoting the appropriate use of antibiotics through dose optimization, therapeutic drug monitoring, antimicrobial de-escalation, intravenous-to-oral switch therapy, and education of healthcare professionals. This review summarizes the risk factors, mechanisms, common resistant pathogens, clinical consequences, prevention strategies, and the role of the clinical pharmacist in combating antimicrobial resistance in the ICU. A multidisciplinary approach is essential to preserve antibiotic effectiveness, improve patient outcomes, and reduce the global burden of antimicrobial resistance.

Keywords: antimicrobial resistance; intensive care unit; multidrug-resistant organisms; antimicrobial stewardship; clinical pharmacist; critical care

1. Introduction

Antimicrobial resistance (AMR) is the ability of microorganisms such as bacteria, viruses, fungi, and parasites to survive and multiply despite exposure to antimicrobial agents that were previously effective against them. AMR is recognized as one of the major global public health threats, leading to increased morbidity, mortality, prolonged hospitalization, and rising healthcare costs [1,2]. The intensive care unit (ICU) is a major hotspot for the emergence and spread of AMR because critically ill patients frequently require broad-spectrum antibiotics, invasive devices, prolonged hospitalization, and mechanical ventilation [3,4]. Inappropriate antibiotic prescribing, prolonged antimicrobial therapy, suboptimal dosing, delayed de-escalation, and poor infection control practices accelerate the development of resistant microorganisms [2,4].

Common multidrug-resistant (MDR) pathogens encountered in ICUs include *Acinetobacter baumannii*, *Pseudomonas aeruginosa*, *Klebsiella pneumoniae*, methicillin-resistant *Staphylococcus aureus* (MRSA), vancomycin-resistant *Enterococcus* (VRE), and carbapenem-resistant Enterobacterales (CRE) [1,3]. Antimicrobial resistance limits therapeutic options, increases the risk of treatment failure, and is associated with higher ICU mortality and longer hospital stays [2,3]. Effective antimicrobial stewardship, infection prevention and control measures, appropriate microbiological diagnosis, and optimized antimicrobial therapy are essential strategies to combat AMR in ICU settings [2,4]. Clinical pharmacists play a vital role in preventing AMR by optimizing antimicrobial selection, dose, duration, de-escalation, therapeutic drug monitoring, and multidisciplinary antimicrobial stewardship interventions [2,5].

The aim of this review is to examine antimicrobial stewardship practices in intensive care units and to highlight the role of clinical pharmacists in improving antibiotic use and reducing antimicrobial resistance. The specific objectives are as follows:

1. To describe the burden of infections in ICU patients;
2. To discuss appropriate empirical antibiotic therapy;
3. To explain antimicrobial de-escalation strategies;
4. To review pharmacokinetic/pharmacodynamic (PK/PD) optimization of antibiotics in critically ill patients;
5. To discuss antimicrobial resistance in the ICU;

6. To highlight the role of clinical pharmacists in antimicrobial stewardship.

2. Methodology

This is a narrative review based on literature published between 2019 and 2024. Relevant publications were identified through searches of PubMed and the World Health Organization (WHO) website using the search terms “antimicrobial resistance,” “ICU,” “stewardship,” and “multidrug resistance,” used individually and in combination. Foundational guideline and pharmacokinetic references published prior to 2019 were also included where they remained the most current authoritative source on the topic. Articles including original research, review papers, and WHO reports addressing antimicrobial resistance, stewardship practices, and clinical pharmacist interventions in intensive care settings were considered for inclusion. As this is a narrative rather than a systematic review, no formal inclusion or exclusion criteria, quality assessment tool, or PRISMA methodology was applied; relevant sources were selected based on their relevance to the review’s objectives.

3. Causes of Antimicrobial Resistance in the ICU

The main causes of antimicrobial resistance (AMR) in the ICU include:

- Frequent use of broad-spectrum antibiotics;
- Unnecessary or inappropriate antibiotic use;
- Long duration of antibiotic treatment;
- Prolonged ICU stay;
- Use of invasive devices such as ventilators and catheters;
- Poor hand hygiene among healthcare workers;
- Spread of resistant bacteria between patients;
- Weak immune system in critically ill patients.

These factors increase the selective pressure on microorganisms, allowing resistant bacteria to survive, multiply, and spread within the ICU environment. The principal resistant organisms are summarized below:

- Methicillin-resistant *Staphylococcus aureus* (MRSA) is one of the leading causes of healthcare-associated pneumonia and bloodstream infections in ICUs.
- Vancomycin-resistant enterococci (VRE) commonly infect patients with prolonged hospitalization or extensive antibiotic exposure.
- Extended-spectrum β -lactamase (ESBL)-producing Enterobacterales hydrolyze many β -lactam antibiotics, limiting treatment options.
- Carbapenem-resistant Enterobacterales (CRE) are considered critical-priority pathogens because they are resistant to carbapenems, which are often the last line of therapy.
- Multidrug-resistant *Pseudomonas aeruginosa* has multiple resistance mechanisms, including efflux pumps, reduced membrane permeability, and enzyme production.
- *Acinetobacter baumannii* survives for long periods on hospital surfaces, facilitating transmission in ICUs.

3.1. Risk Factors for AMR in the ICU

Several factors contribute to the emergence of antimicrobial resistance in critically ill patients.

Patient-related factors: advanced age, diabetes mellitus, chronic kidney disease, malignancy, immunosuppression, and malnutrition.

Treatment-related factors: broad-spectrum antibiotic exposure, prolonged antibiotic therapy, multiple antibiotic combinations, inadequate dosing, and delayed de-escalation.

ICU-related factors: mechanical ventilation, central venous catheters, urinary catheters, extracorporeal membrane oxygenation (ECMO), hemodialysis, prolonged ICU stay, and cross-transmission between patients.

3.2. Common ICU Infections and Causative Pathogens

Table 1 summarizes the common infections encountered in the ICU and their predominant causative pathogens.

Table 1. Common ICU infections and their predominant causative pathogens.

ICU infection	Major causative pathogens	Key clinical highlights
Ventilator-associated pneumonia (VAP)	<i>Pseudomonas aeruginosa</i> , <i>Acinetobacter baumannii</i> , <i>Klebsiella pneumoniae</i> , MRSA	Most common ICU-acquired infection; associated with mechanical ventilation
Hospital-acquired pneumonia (HAP)	<i>P. aeruginosa</i> , <i>K. pneumoniae</i> , <i>A. baumannii</i> , MRSA	Develops ≥ 48 h after admission; high mortality if therapy is delayed
Bloodstream infection (BSI)	<i>Staphylococcus aureus</i> , CoNS, <i>E. coli</i> , <i>K. pneumoniae</i> , <i>Candida</i> spp.	High mortality; often secondary to invasive devices or other infections
Catheter-related bloodstream infection (CRBSI)	CoNS, <i>S. aureus</i> , <i>Candida</i> spp., <i>Enterococcus</i> spp.	Strongly associated with central venous catheters
Catheter-associated urinary tract infection (CAUTI)	<i>E. coli</i> , <i>Proteus mirabilis</i> , <i>K. pneumoniae</i> , <i>P. aeruginosa</i> , <i>Candida</i> spp.	Most common device-associated UTI; prolonged catheterization is the main risk factor
Intra-abdominal infection	<i>E. coli</i> , <i>Bacteroides fragilis</i> , <i>Enterococcus faecalis</i> , <i>K. pneumoniae</i>	Requires antimicrobial therapy plus surgical or radiological source control
Surgical site infection (SSI)	<i>S. aureus</i> , CoNS, <i>E. coli</i> , <i>Enterococcus</i> spp.	Common postoperative complication that increases hospital stay and cost
Sepsis and septic shock	Mixed Gram-positive, Gram-negative bacteria, and fungi	Medical emergency requiring early recognition, prompt antibiotics, and source control

Abbreviations: CoNS, coagulase-negative staphylococci; MRSA, methicillin-resistant *Staphylococcus aureus*.

3.3. Common Resistant Pathogens in ICUs

Critically ill patients admitted to the ICU are highly susceptible to infections caused by multidrug-resistant (MDR) pathogens [6–8]. The frequent use of broad-spectrum antibiotics, prolonged hospitalization, invasive medical devices, and weakened immune systems create favorable conditions for the emergence and spread of resistant microorganisms. These pathogens are responsible for healthcare-associated infections such as ventilator-associated pneumonia (VAP), catheter-associated urinary tract infections (CAUTI), central line-associated bloodstream infections (CLABSI), and surgical site infections (SSI). Infections caused by resistant organisms are associated with increased mortality, longer ICU stays, higher healthcare costs, and limited treatment options. Table 2 lists the common resistant pathogens in the ICU and the preferred antimicrobial treatment options.

Table 2. Common resistant pathogens in the ICU and preferred antimicrobial treatment.

Pathogen	Resistance	Common ICU infections	Preferred treatment
MRSA	Methicillin resistant	VAP, bloodstream infection, SSI	Vancomycin, linezolid
VRE	Vancomycin resistant	UTI, bloodstream infection	Linezolid, daptomycin
ESBL-producing <i>E. coli</i> / <i>K. pneumoniae</i>	Resistant to penicillins and cephalosporins	UTI, sepsis, pneumonia	Meropenem, imipenem
CRE	Resistant to carbapenems	Pneumonia, bloodstream infection, UTI	Ceftazidime–avibactam, meropenem–vaborbactam

Pathogen	Resistance	Common ICU infections	Preferred treatment
MDR <i>Pseudomonas aeruginosa</i>	Multiple drug resistance	VAP, sepsis	Ceftolozane–tazobactam, cefiderocol
MDR <i>Acinetobacter baumannii</i>	Carbapenem resistant	VAP, bloodstream infection	Sulbactam, colistin, cefiderocol

Abbreviations: CRE, carbapenem-resistant Enterobacterales; ESBL, extended-spectrum β -lactamase; MDR, multidrug-resistant; MRSA, methicillin-resistant *Staphylococcus aureus*; SSI, surgical site infection; UTI, urinary tract infection; VAP, ventilator-associated pneumonia; VRE, vancomycin-resistant *Enterococcus*.

4. Effects of Antimicrobial Resistance in the ICU

Antimicrobial resistance has serious consequences for critically ill patients in the ICU. When bacteria become resistant to antibiotics, infections become more difficult to treat, resulting in delayed recovery and poor clinical outcomes. Resistant infections often require the use of expensive last-line antibiotics, prolonged hospitalization, and intensive supportive care. AMR also increases the risk of healthcare-associated infections, treatment failure, and mortality. Therefore, controlling antimicrobial resistance is essential to improve patient safety and reduce the burden on healthcare systems. In particular:

- AMR reduces the effectiveness of standard antibiotic therapy.
- Delayed appropriate treatment increases the risk of complications and death.
- ICU patients with MDR infections have longer durations of mechanical ventilation and longer hospital stays.
- Resistant infections require the use of reserve antibiotics, which are more expensive and may cause severe adverse effects.
- Effective antimicrobial stewardship and infection prevention programs can reduce the burden of AMR in ICUs.

5. Mechanisms of Antimicrobial Resistance

The principal mechanisms by which bacteria resist antimicrobial agents are summarized in Table 3.

Table 3. Mechanisms of antimicrobial resistance (AMR).

Mechanism	Description	Example of resistant organism	Antibiotics affected
Enzymatic degradation	Bacteria produce enzymes that break down or destroy antibiotics before they can act.	ESBL-producing <i>Escherichia coli</i> , carbapenem-resistant Enterobacterales (CRE)	Penicillins, cephalosporins, carbapenems
Alteration of target site	Bacteria change the antibiotic's binding site, preventing the drug from working effectively.	MRSA, VRE	β -lactams, vancomycin, macrolides
Efflux pumps	Bacteria actively pump antibiotics out of the cell, reducing the drug concentration inside the bacteria.	<i>Pseudomonas aeruginosa</i> , <i>Acinetobacter baumannii</i>	Fluoroquinolones, tetracyclines, macrolides
Reduced permeability	Changes in the bacterial outer membrane reduce antibiotic entry into the cell.	<i>Klebsiella pneumoniae</i> , <i>Pseudomonas aeruginosa</i>	Carbapenems, aminoglycosides
Biofilm formation	Bacteria form a protective layer (biofilm) on medical devices, making antibiotics less effective.	<i>Staphylococcus aureus</i> , <i>Pseudomonas aeruginosa</i>	Multiple antibiotic classes
Genetic mutation and horizontal gene transfer	Resistance genes spread between bacteria through plasmids, transposons, or bacteriophages, allowing rapid development of resistance.	<i>Escherichia coli</i> , <i>Klebsiella pneumoniae</i> , enterococci	Multiple antibiotic classes

6. Burden of Infections in ICU Patients

ICU patients are at a high risk of developing infections due to critical illness, weakened immune function, and multiple comorbidities [1]. The use of invasive devices such as mechanical ventilators, central venous catheters, and urinary catheters significantly increases the risk of healthcare-associated infections (HAIs) [2]. The most common ICU-acquired infections include ventilator-associated pneumonia (VAP), catheter-associated urinary tract infection (CA-UTI), central line-associated bloodstream infection (CLABSI), and surgical site infection (SSI) [2,3]. Healthcare-associated infections contribute to prolonged ICU stay, increased hospital costs, higher morbidity, and increased mortality [2].

Early empirical use of broad-spectrum antibiotics is common in critically ill patients but may promote the emergence of MDR organisms if not optimized [1,4]. Common multidrug-resistant pathogens in ICUs include *Acinetobacter baumannii*, *Pseudomonas aeruginosa*, *Klebsiella pneumoniae*, MRSA, and VRE [3,4]. Antimicrobial stewardship, infection prevention measures, and timely microbiological diagnosis are essential to reduce infection rates and improve patient outcomes in the ICU [1,4]. Clinical pharmacists play a vital role by optimizing antimicrobial therapy, monitoring treatment effectiveness, preventing medication errors, and supporting antimicrobial stewardship programs [1,5].

7. Empirical Antibiotic Therapy in the ICU

Empirical antibiotic therapy is defined as treatment with antimicrobials before the organism is identified, considering the most probable etiological agent and the degree of severity of the disease [1,2]. Selection of empirical therapy must take into account the likely sources of infection (for example, respiratory tract, urine, intra-abdominal, bloodstream), the patient's risk factors for MDR organisms, local antibiogram data, and the degree of severity of the presentation [2,3]. In the case of sepsis or septic shock, antibiotics must be started within one hour of diagnosis, since delay in their administration increases the mortality rate [6].

Indications for broader empirical therapy for MDR infections include prior antibiotic use within 90 days, prolonged stay in hospital, recent ICU admission, presence of invasive devices, and previous colonization with resistant microorganisms [2,4]. Combination therapy (such as broad-spectrum β -lactams plus aminoglycosides or fluoroquinolones) can be chosen in critical care patients at risk of *Pseudomonas aeruginosa* infection and in septic shock patients, but this strategy should be reconsidered once susceptibility data are available [1,3]. Empirical regimens should be re-evaluated after receiving culture and susceptibility data within 48–72 h of treatment onset, in order to de-escalate to a narrower spectrum of treatment [2,3]. Clinical pharmacists help in choosing empirical therapy by considering local resistance patterns, recommending therapy according to guidelines, and adjusting the dose according to renal and/or hepatic dysfunction at initiation of the drug [1,5].

8. Antimicrobial De-Escalation Strategies

The key elements of antimicrobial de-escalation are illustrated in Figure 1 and described below.

- Reassess antimicrobial therapy within 48–72 h of initiation using clinical response, microbiological culture results, and antimicrobial susceptibility testing [1,2].
- Switch from broad-spectrum to narrow-spectrum antibiotics once the causative pathogen and its susceptibility pattern have been identified, to minimize unnecessary antimicrobial exposure [2,3].
- Discontinue unnecessary combination therapy when a single antimicrobial agent provides adequate coverage, thereby reducing toxicity and the risk of antimicrobial resistance [2,4].
- Stop antimicrobial therapy if culture results are negative and clinical evaluation indicates that a bacterial infection is unlikely [1,3].
- Optimize the duration of therapy according to evidence-based guidelines and the patient's clinical response to avoid prolonged antibiotic use [1,2].
- Perform an IV-to-oral switch when the patient is clinically stable, able to tolerate oral medications, and an appropriate oral antimicrobial with good bioavailability is available.
- Monitor clinical improvement through assessment of fever, white blood cell count, inflammatory markers (e.g., procalcitonin), organ function, and microbiological findings to ensure the effectiveness of de-escalated therapy [1,5].
- Clinical pharmacists should participate in antimicrobial stewardship rounds by reviewing antimicrobial therapy, recommending de-escalation, optimizing doses, and monitoring for adverse drug reactions and drug interactions [2,4].

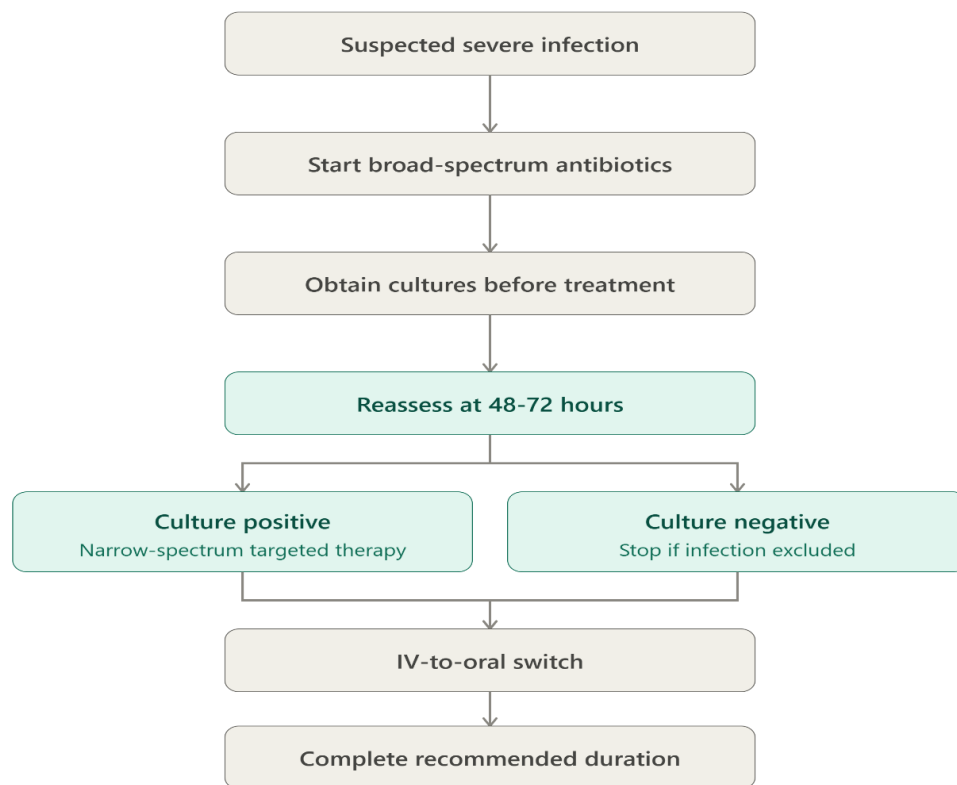


Figure 1. Antimicrobial de-escalation strategy.

9. Role of Clinical Pharmacists in Antimicrobial Stewardship

The contributions of clinical pharmacists to antimicrobial stewardship are summarized in Figure 2. They include the following:

- Reviewing and optimizing antimicrobial prescriptions based on the patient's clinical condition, culture reports, and local antibiogram [2,5].
- Recommending appropriate empirical antibiotics and guiding culture-directed therapy according to antimicrobial susceptibility results [1,2].
- Optimizing antimicrobial dosing using PK/PD principles (Figure 3) and adjusting doses in renal or hepatic impairment [5,9].
- Promoting antimicrobial de-escalation, IV-to-oral switch therapy, and appropriate duration of treatment to minimize unnecessary antibiotic exposure [2,4].
- Monitoring therapeutic drug levels (e.g., vancomycin and aminoglycosides), adverse drug reactions, and drug-drug interactions to improve treatment safety and efficacy [5,9].
- Participating in multidisciplinary ICU rounds, educating healthcare professionals, conducting antimicrobial audits with feedback, and supporting antimicrobial stewardship programs to reduce antimicrobial resistance and improve patient outcomes [2,4,5].

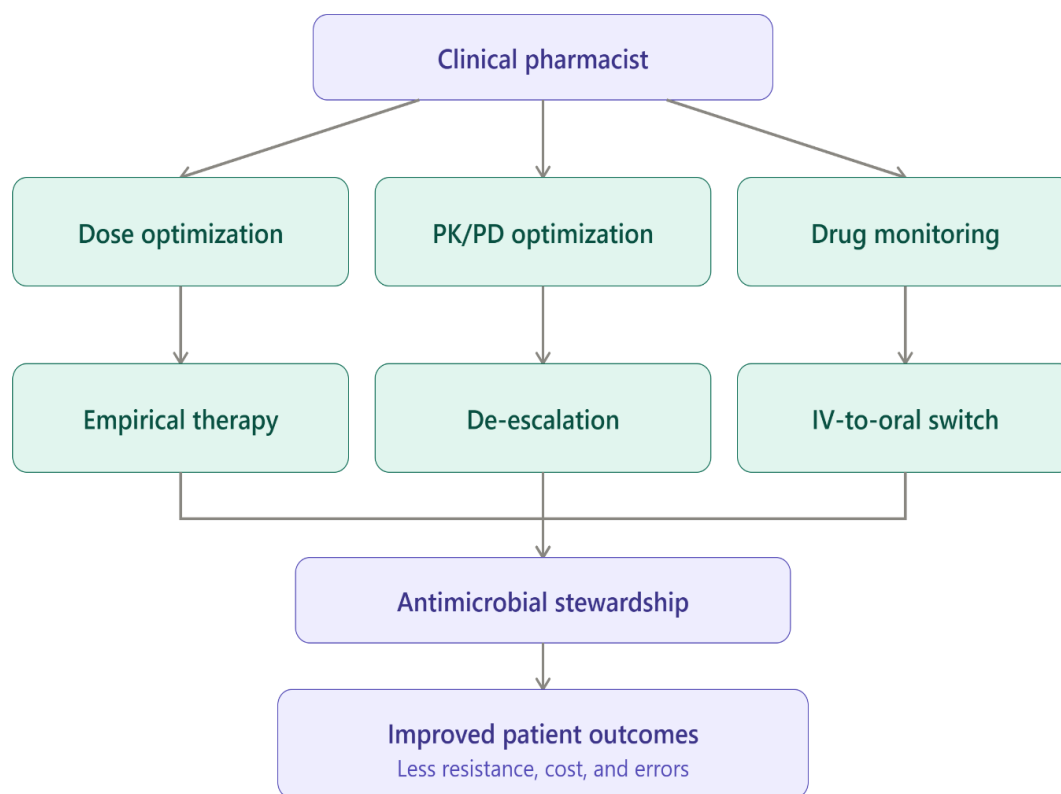


Figure 2. Clinical pharmacist's role in antimicrobial stewardship.

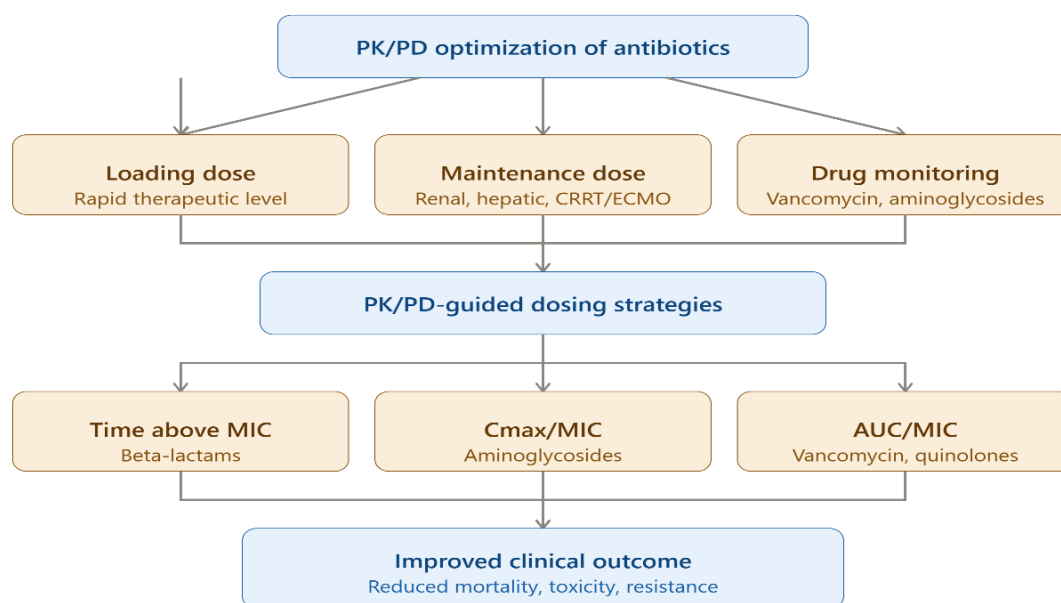


Figure 3. PK/PD optimization of antibiotics in critically ill patients [5].

10. Antimicrobial Resistance in the ICU

Critically ill patients are at a high risk of developing antimicrobial-resistant infections due to severe illness, prolonged ICU stay, invasive devices, and frequent exposure to broad-spectrum antibiotics [1,2]. Common MDR pathogens in ICUs include *Acinetobacter baumannii*, *Pseudomonas aeruginosa*, *Klebsiella pneumoniae*, MRSA, VRE, and CRE [2,3]. Inappropriate antibiotic prescribing, prolonged antibiotic therapy, inadequate dosing, and delayed de-escalation contribute significantly to the emergence and spread of antimicrobial resistance [1,4]. Antimicrobial resistance is associated with increased morbidity, mortality, prolonged hospitalization, higher healthcare costs, and limited treatment options in critically ill patients [2,3]. Early microbiological diagnosis, antimicrobial stewardship, infection prevention measures, and adherence to evidence-based treatment guidelines are essential to reduce the burden of AMR in ICUs [1,4].

11. Clinical Consequences of Antimicrobial Resistance in the ICU

The clinical consequences of AMR in the ICU include [3,4,6]:

- Delayed initiation of effective antimicrobial therapy;
- Increased ICU and hospital mortality;
- Prolonged ICU and hospital length of stay;
- Higher risk of treatment failure and recurrent infections;
- Increased incidence of severe sepsis and septic shock;
- Limited therapeutic options due to multidrug-resistant (MDR), extensively drug-resistant (XDR), and pan-drug-resistant (PDR) pathogens;
- Greater use of toxic reserve antibiotics (e.g., colistin and polymyxins), increasing adverse drug reactions;
- Increased healthcare costs due to prolonged hospitalization, isolation measures, and expensive antimicrobial therapy;
- Higher risk of transmission of resistant organisms, leading to healthcare-associated outbreaks;
- Reduced quality of patient care and increased burden on healthcare systems.

12. Intravenous-to-Oral Switch Therapy

12.1. IV-to-Oral Antimicrobial Equivalents

Table 4 lists commonly used IV antimicrobials, their oral equivalents, oral bioavailability, and common indications in ICU patients.

Table 4. IV-to-oral antimicrobial equivalents and bioavailability in ICU patients.

IV antimicrobial	Oral equivalent	Oral bioavailability	Common indications
Levofloxacin	Levofloxacin	~99%	Pneumonia, urinary tract infections, skin and soft tissue infections
Ciprofloxacin	Ciprofloxacin	70–80%	Urinary tract infections, intra-abdominal infections, <i>Pseudomonas</i> infections
Linezolid	Linezolid	~100%	MRSA pneumonia, skin and soft tissue infections, VRE infections
Metronidazole	Metronidazole	~100%	Anaerobic infections, intra-abdominal infections
Fluconazole	Fluconazole	>90%	Candidiasis, fungal infections
Doxycycline	Doxycycline	90–100%	Community-acquired pneumonia, atypical respiratory infections
Clindamycin	Clindamycin	~90%	Skin and soft tissue infections, anaerobic infections

IV antimicrobial	Oral equivalent	Oral bioavailability	Common indications
Trimethoprim–sulfamethoxazole	Trimethoprim–sulfamethoxazole	90–100%	Urinary tract infections, <i>Pneumocystis jirovecii</i> pneumonia, MRSA infections
Azithromycin	Azithromycin	~37% (high tissue penetration)	Community-acquired pneumonia, atypical respiratory infections

12.2. Criteria for IV-to-Oral Switch

- Hemodynamically stable;
- Afebrile for 24–48 h;
- Clinical signs and symptoms improving;
- Functioning gastrointestinal tract with adequate oral absorption;
- Able to swallow or receive enteral medications;
- Appropriate oral antimicrobial available with good bioavailability;
- Culture and susceptibility results support oral therapy.

12.3. Role of the Clinical Pharmacist in IV-to-Oral Switch

- Assess patient eligibility for IV-to-oral conversion;
- Review culture and susceptibility reports;
- Select an appropriate oral antimicrobial with adequate bioavailability;
- Optimize dose according to renal and hepatic function;
- Monitor treatment response and adverse drug reactions;
- Educate healthcare professionals and promote IV-to-oral switch protocols as part of antimicrobial stewardship.

13. Clinical Pharmacist's Role in Infection Prevention and Control

1. Support infection prevention and control measures by promoting adherence to hand hygiene protocols and aseptic technique during medication administration [2,4].
2. Encourage timely removal of unnecessary invasive devices, such as urinary catheters and central lines, by flagging device duration during medication reviews [1,2].
3. Promote collection of appropriate microbiological cultures before antibiotic initiation, ensuring empirical therapy decisions are supported by diagnostic data [1].
4. Reinforce ventilator and catheter care bundle compliance as part of broader ICU rounds, working alongside nursing and infection control teams [2,4].
5. Contribute to hospital antibiograms by helping track local resistance trends, which informs both empirical prescribing and infection control priorities [2,5].
6. Collaborate with microbiologists and infection control personnel to identify outbreaks of resistant organisms early and support containment measures [4,5].

14. Clinical Pharmacist's Advocacy and Communication with Prescribers

1. Advise prescribers against initiating antibiotics for suspected viral or non-bacterial infections, using clinical and laboratory evidence to support the discussion [1,2].

2. Prompt physicians to reassess antibiotic therapy at 48–72 h, using culture results and clinical trajectory to guide continuation, modification, or discontinuation [2,3].
3. Provide antibiogram-based guidance to prescribers at the point of empirical antibiotic selection, particularly for patients with risk factors for MDR organisms [1,2].
4. Flag opportunities for de-escalation or IV-to-oral conversion directly to the prescribing team once susceptibility data or clinical stability criteria are met [2,5].
5. Deliver structured feedback to prescribers through antimicrobial audit-and-feedback cycles, highlighting deviations from guideline-recommended duration or dosing [2,3].
6. Represent pharmacy input in multidisciplinary stewardship committee discussions, contributing to the development and revision of hospital antibiotic guidelines [2,3].

15. Conclusions

Antimicrobial stewardship is a fundamental component of infection management in intensive care units, ensuring the appropriate selection, dosing, route, and duration of antimicrobial therapy. Strategies such as timely empirical antibiotic therapy, culture-guided treatment, antimicrobial de-escalation, IV-to-oral switch therapy, and pharmacokinetic/pharmacodynamic (PK/PD) optimization are essential for improving clinical outcomes while minimizing antimicrobial resistance. These interventions help reduce medication-related adverse events, healthcare costs, and the emergence of multidrug-resistant organisms.

Clinical pharmacists play a pivotal role in antimicrobial stewardship by optimizing antimicrobial therapy, monitoring therapeutic response, interpreting microbiological and therapeutic drug monitoring data, recommending dose adjustments, facilitating de-escalation and IV-to-oral conversion, and collaborating with the multidisciplinary ICU team. Through active participation in antimicrobial stewardship programs, clinical pharmacists contribute significantly to improving patient safety, preserving antimicrobial effectiveness, and enhancing the quality of critical care. Continued implementation of evidence-based stewardship practices and multidisciplinary collaboration is essential to combat antimicrobial resistance and improve outcomes in critically ill patients.

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Conceptualization, V.V.Sathyaseelan.; writing—original draft preparation, V.V.Sathyaseelan and R.Swaathi visualization (tables), R.Swaathi writing—review and editing, supervision, G.R.Haripriya All authors have read and agreed to the published version of the manuscript.

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The authors declare no conflicts of interest.

Abbreviations:

The following abbreviations are used in this manuscript:

AMR	Antimicrobial resistance
CAUTI	Catheter-associated urinary tract infection
CLABSI	Central line-associated bloodstream infection

CoNS	Coagulase-negative staphylococci
CRE	Carbapenem-resistant Enterobacterales
ECMO	Extracorporeal membrane oxygenation
ESBL	Extended-spectrum β -lactamase
HAI	Healthcare-associated infection
ICU	Intensive care unit
MDR	Multidrug-resistant
MRSA	Methicillin-resistant <i>Staphylococcus aureus</i>
PDR	Pan-drug-resistant
PK/PD	Pharmacokinetic/pharmacodynamic
SSI	Surgical site infection
VAP	Ventilator-associated pneumonia
VRE	Vancomycin-resistant <i>Enterococcus</i>
XDR	Extensively drug-resistant

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