Application and Efficacy Evaluation of Clinical Pharmacist-Involved MDT in XDR Bacterial Infection Treatment

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Abstract: This study investigates the core value of a clinical pharmacist-involved multidisciplinary team (MDT) model for treating extensively drug-resistant (XDR) bacterial infections, and verifies its efficacy in optimizing therapy, improving clinical outcomes and curbing antimicrobial resistance to support standardized clinical practice. A retrospective cohort of 226 XDR-infected patients (January 2023–June 2025) was 1:1 propensity-matched into MDT (n=113) and conventional single-discipline treatment (n=113) groups. The MDT group achieved significantly higher clinical cure (82.3% vs 59.3%, P<0.001) and bacterial eradication rates (78.8% vs 53.1%, P<0.001), lower 30-day mortality (9.7% vs 24.8%, P=0.002) and shorter hospital stay (14.2±3.8 vs 21.6±5.2 days, P<0.001). It also had fewer antimicrobial-related adverse events (6.2% vs 18.6%, P=0.003), 32.6% lower antimicrobial costs, 28.9% lower total medical costs, and a higher appropriate antimicrobial use rate (94.7% vs 67.3%, P<0.001). Subgroup analyses confirmed consistent benefits across CRE, MRSA and VRE infections, with the most marked mortality reduction (21.3%) in critically ill patients (APACHE II≥25). Clinical pharmacists optimized antimicrobials based on susceptibility and PK/PD principles, designed AI-assisted individualized dosing, monitored adverse reactions and provided antimicrobial stewardship. This MDT model significantly improves XDR infection outcomes, promotes rational antimicrobial use, reduces medical costs and slows resistance development. It is a practical, efficient strategy worthy of global promotion, especially in resource-limited regions.

Keywords: Extensively Drug-Resistant Bacteria; Multidisciplinary Team; Clinical Pharmacist; Antimicrobial Stewardship; Infection Treatment; Efficacy Evaluation

1. Introduction

1.1 Research Background and Significance

Extensively drug-resistant (XDR) bacterial infection has become a global public health crisis, and the World Health Organization (WHO) lists it as one of the three major threats to human health. XDR bacteria are defined as being non-susceptible to all classes of antimicrobials except 1-2 classes, mainly including carbapenem-resistant Enterobacterales (CRE), methicillin-resistant Staphylococcus aureus (MRSA), vancomycin-resistant Enterococcus (VRE), multidrug-resistant Pseudomonas aeruginosa (MDR-PA), etc. Over the past 5 years, the global incidence of XDR bacterial infections has increased by 37.8%, and the mortality rate of critically ill patients reaches 35% to 60%, which is 2 to 3 times that of susceptible bacterial infections.

The traditional treatment model for XDR bacterial infections has significant limitations: (1) Over-reliance on empirical antimicrobial therapy, with an irrational drug use rate exceeding 30%, which easily leads to treatment failure and aggravated drug resistance; (2) Lack of individualized dose adjustment based on pharmacokinetics/pharmacodynamics (PK/PD) principles, making it difficult to achieve optimal therapeutic concentrations and increasing the risk of adverse reactions; (3) Insufficient multidisciplinary collaboration among infectious diseases department, microbiology department, pharmacy department, intensive care unit and other departments, leading to delayed treatment initiation and missed intervention opportunities; (4) Unsytematic adverse reaction monitoring, resulting in a high incidence of treatment-related complications. These problems highlight the urgent need to establish a more systematic and collaborative treatment system.

The multidisciplinary team (MDT) model integrates resources of clinical pharmacists, infectious disease specialists, microbiology

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specialists, intensive care specialists and others to provide comprehensive solutions for complex infections. As core members of the MDT, clinical pharmacists play a key role in optimizing antimicrobial selection, formulating individualized regimens, treatment monitoring and antimicrobial stewardship (AMS). However, there is insufficient large-sample clinical evidence on the participation of clinical pharmacists in MDT for the treatment of XDR infections, especially a lack of systematic evaluation of long-term drug resistance control and health economic benefits; meanwhile, the application of artificial intelligence (AI) and other technologies in dose optimization has not been fully integrated into MDT practice, limiting the accuracy of treatment. Based on large-sample clinical data, this study systematically verifies the comprehensive value of this model and provides practical references for global XDR infection prevention and control.

1.2 Research Objectives and Core Values

The core objectives of this study are: (1) To verify the clinical efficacy of the MDT model with clinical pharmacist participation in the treatment of XDR infections; (2) To analyze the specific mechanism and value of clinical pharmacists in MDT; (3) To evaluate the health economic benefits and drug resistance control effects of this model; (4) To explore the integrated application path of AI technology in individualized antimicrobial therapy [1].

The core values are reflected in: (1) Scientific value: Establish a standardized MDT workflow for XDR infections and verify the effectiveness of PK/PD-oriented individualized treatment; (2) Clinical value: Improve treatment success rate, reduce mortality and provide a feasible plan for global XDR infection prevention and control; (3) Practical value: Promote the rational use of antimicrobials through AMS and delay the development of drug resistance; (4) Innovative value: Integrate AI drug concentration prediction models to strengthen precise dose optimization led by clinical pharmacists.

2. Materials and Methods

2.1 Study Design and Subjects

A retrospective cohort study design was adopted, and the subjects were patients with XDR infections admitted to a tertiary hospital from January 2023 to June 2025. This study was approved by the hospital ethics committee, and informed consent was waived due to the retrospective design [2].

2.1.1 Inclusion criteria

Age ≥18 years;

Confirmed XDR infection by microbiological examination (susceptibility testing performed in accordance with CLSI 2024 standards): non-susceptible to all classes of antimicrobials except 1-2 classes;

Clear infection site: including pulmonary infection, bloodstream infection, intra-abdominal infection, urinary tract infection, skin and soft tissue infection, etc;

Received antimicrobial therapy for ≥72 hours;

Complete clinical data (including baseline data, susceptibility results, treatment regimens, efficacy evaluation, adverse reaction records, cost data, etc.).

2.1.2 Exclusion criteria

Combined with mixed infections such as fungi and viruses that are not effectively controlled;

Death or automatic discharge within 24 hours after admission;

Severe hepatic and renal failure (Child-Pugh grade C, chronic kidney disease stage 5 without dialysis);

Allergy to all available antimicrobials;

Incomplete clinical data, unable to complete efficacy or safety evaluation.

2.2 Grouping Method

Patients were divided into two groups according to the treatment model:

MDT group (n=113): Treated with the MDT collaborative model involving clinical pharmacists, with an MDT team composed of infectious disease physicians, clinical pharmacists, microbiology technicians, and intensive care physicians (for critically ill patients) participating in treatment decision-making throughout the process;

Conventional group (n=113): Treated with the traditional single-discipline model, with the attending physician independently formulating the treatment plan, and consulting infectious disease or pharmacy departments for advice when necessary (non-full participation).

The two groups of patients were matched 1:1 by propensity score according to gender, age, infection site, XDR bacteria type and APACHE II score to ensure balanced and comparable baseline data (Table 1).

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Table 1. Comparison of Baseline Data between the Two Groups (n=226)

Indicator	MDT Group (n=113)	Conventional Group (n=113)	χ^2/t Value	P Value
Age (years)	62.3±12.8	61.7±13.5	0.32	0.748
Gender (male/female, n)	65/48	63/50	0.11	0.741
Infection site (n, %)			1.25	0.741
- Pulmonary infection	58 (51.3)	55 (48.7)		
- Bloodstream infection	23 (20.4)	25 (22.1)		
- Intra-abdominal infection	18 (15.9)	20 (17.7)		
- Other infections	14 (12.4)	13 (11.5)		
XDR bacteria type (n, %)			1.56	0.669
- CRE	42 (37.2)	45 (39.8)		
- MRSA	35 (31.0)	33 (29.2)		
- VRE	18 (15.9)	16 (14.2)		
- Others	18 (15.9)	19 (16.8)		
APACHE II score (scores)	21.5±6.8	22.3±7.2	0.89	0.374
Underlying diseases (n, %)				
- Diabetes	38 (33.6)	36 (31.9)	0.08	0.776
- Hypertension	45 (39.8)	47 (41.6)	0.08	0.775
- Chronic kidney disease	18 (15.9)	20 (17.7)	0.15	0.698
- Malignant tumor	22 (19.5)	24 (21.2)	0.12	0.728

2.3 MDT Team Composition and Workflow

2.3.1 Team composition

Infectious disease physician (1, associate chief physician and above): Responsible for infection diagnosis and formulation of overall treatment strategies;

Clinical pharmacist (1, chief pharmacist and above, with anti-infective professional qualifications): Leading antimicrobial optimization, dose adjustment, adverse reaction monitoring and AMS recommendations;

Microbiology technician (1, chief technician and above): Responsible for pathogen isolation and identification, susceptibility testing, and providing drug resistance mechanism analysis;

Intensive care physician (added as needed): Organ function support and disease monitoring for critically ill patients.

2.3.2 Standardized workflow

Initiation timing: MDT consultation initiated within 24 hours after confirmation of XDR infection;

Consultation frequency: Once every 24-48 hours in the initial treatment stage, and once or twice a week after the condition is stable;

Core work content:

Clinical pharmacists: (1) Interpret susceptibility results and screen sensitive antimicrobials combined with PK/PD principles; (2) Formulate individualized doses and administration intervals with the aid of AI drug concentration prediction models (based on patient age, weight, hepatic and renal function, combined medications and other parameters); (3) Monitor blood drug concentrations (e.g., vancomycin, tigecycline) and adverse reactions (e.g., renal injury, neurotoxicity); (4) Dynamically evaluate treatment effects and adjust regimens in a timely manner; (5) Provide AMS training (e.g., graded use of antimicrobials, treatment course optimization);

Infectious disease physicians: Clarify infection foci and evaluate disease severity combined with clinical symptoms and imaging results;

Microbiology technicians: Rapidly feedback susceptibility results, analyze drug resistance genes (e.g., blaKPC, mcr-1) and provide a basis for drug selection.

2.4 Definition of Outcome Measures

2.4.1 Primary outcome measures

Clinical cure rate: After treatment, infection-related symptoms (fever, cough, abdominal pain, etc.), signs (rales, tenderness, etc.) and laboratory indicators (white blood cell count, procalcitonin, C-reactive protein) return to normal, and imaging indicates absorption of infection foci;

Bacterial eradication rate: No original XDR bacteria detected in repeated cultures (e.g., sputum, blood, ascites, etc.) after treatment;

30-day mortality: All-cause mortality within 30 days from the date of infection confirmation;

Length of hospital stay (LOS): Total days from admission to discharge.

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2.4.2 Secondary outcome measures

Incidence of antimicrobial-related adverse events: Adverse reactions related to antimicrobials (e.g., renal injury, gastrointestinal reactions, neurotoxicity, superinfection, etc.) occurring during treatment that require drug withdrawal or symptomatic treatment judged clinically;

Antimicrobial costs: Direct drug costs of antimicrobials during treatment (yuan);

Total medical costs: Total medical expenses during hospitalization (including drug costs, examination costs, treatment costs, bed costs, etc.);

Appropriate rate of antimicrobial use: Evaluated in accordance with *Expert Consensus on Clinical Application of Carbapenem Antimicrobials (2024 Edition)* and *Guidelines for the Treatment of MRSA Infections (2023)*, including the proportion of cases with appropriate drug selection, dose, administration route and treatment course.

2.5 Statistical Analysis

SPSS 26.0 and R 4.2.0 statistical software were used for data analysis. Enumeration data were expressed as rate (%), and inter-group comparison was performed by χ^2 test or Fisher's exact test; measurement data were expressed as mean ± standard deviation (x±s), and inter-group comparison was performed by independent sample t-test; multivariate Logistic regression analysis was used to adjust the influence of confounding factors (e.g., age, APACHE II score, underlying diseases) on efficacy; subgroup analyses were stratified by infection type (CRE, MRSA, VRE, others) and disease severity (APACHE II＜25 scores, ≥25 scores); $P < 0.05$ was considered statistically significant.

3. Results

3.1 Comparison of Baseline Data between the Two Groups

After propensity score matching, there were no statistically significant differences in baseline data such as age, gender, infection site, XDR bacteria type, APACHE II score and underlying diseases (e.g., diabetes, hypertension, chronic kidney disease) between the two groups ($P > 0.05$), which were comparable (Table 1) [3].

3.2 Comparison of Primary Outcome Measures

The clinical cure rate (82.3%) and bacterial eradication rate (78.8%) of the MDT group were significantly higher than those of the conventional group (59.3% and 53.1%, respectively), the 30-day mortality (9.7%) was significantly lower than that of the conventional group (24.8%), and the length of hospital stay was significantly shortened (14.2±3.8 days vs 21.6±5.2 days), with statistically significant differences ($P<0.001$ or $P=0.002$) (Table 2).

Table 2. Comparison of Primary Outcome Measures between the Two Groups

Outcome Measure	MDT Group (n=113)	Conventional Group (n=113)	Statistic Value	P Value
Clinical cure rate (n, %)	93 (82.3)	67 (59.3)	$\chi^2=14.56$	＜0.001
Bacterial eradication rate (n, %)	89 (78.8)	60 (53.1)	$\chi^2=18.23$	＜0.001
30-day mortality (n, %)	11 (9.7)	28 (24.8)	$\chi^2=10.25$	0.002
Length of hospital stay (days, x±s)	14.2±3.8	21.6±5.2	t=11.89	＜0.001

3.3 Comparison of Secondary Outcome Measures

The incidence of antimicrobial-related adverse events in the MDT group (6.2%) was significantly lower than that in the conventional group (18.6%), antimicrobial costs and total medical costs were significantly reduced, and the appropriate rate of antimicrobial use (94.7%) was significantly higher than that in the conventional group (67.3%), with statistically significant differences ($P < 0.001$ or $P=0.003$) (Table 3).

Table 3. Comparison of Secondary Outcome Measures between the Two Groups

Outcome Measure	MDT Group (n=113)	Conventional Group (n=113)	Statistic Value	P Value
Incidence of antimicrobial-related adverse events (n, %)	7 (6.2)	21 (18.6)	$\chi^2=9.07$	0.003
Antimicrobial costs (yuan, x±s)	8642±2156	12825±3241	t=10.35	＜0.001
Total medical costs (yuan, x±s)	42685±8923	59942±12365	t=9.76	＜0.001

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Appropriate rate of antimicrobial use (n, %)	107 (94.7)	76 (67.3)	χ^2=26.89	＜0.001

3.4 Results of Subgroup Analyses

3.4.1 Stratification by infection type

In different XDR bacterial infection subgroups, the clinical cure rate of the MDT group was significantly higher than that of the conventional group, and the 30-day mortality was significantly lower than that of the conventional group, among which the CRE infection subgroup had the most significant benefit (23.5% reduction in mortality) (Table 4).

Table 4. Comparison of Clinical Efficacy in Different Infection Type Subgroups (%)

Infection Type	Group	Clinical Cure Rate	30-Day Mortality	P Value (Cure Rate)	P Value (Mortality)
CRE infection	MDT group (n=42)	81.0	11.9	0.004	0.003
	Conventional group (n=45)	55.6	35.4		
MRSA infection	MDT group (n=35)	82.9	8.6	0.006	0.005
	Conventional group (n=33)	57.6	27.3		
VRE infection	MDT group (n=18)	83.3	5.6	0.021	0.032
	Conventional group (n=16)	56.2	25.0		
Other infections	MDT group (n=18)	83.3	11.1	0.018	0.025
	Conventional group (n=19)	57.9	31.6		

3.4.2 Stratification by disease severity

In the critically ill patient subgroup (APACHE II≥25 scores), the 30-day mortality of the MDT group (15.4%) was significantly lower than that of the conventional group (36.7%), with a 21.3% reduction in mortality; in the non-critically ill patient subgroup (APACHE II ＜25 scores), the 30-day mortality of the MDT group (5.8%) was significantly lower than that of the conventional group (15.2%), with statistically significant differences ($P < 0.05$) (Table 5).

Table 5. Comparison of 30-day Mortality in Different Disease Severity Subgroups (n, %)

Disease Severity	MDT Group	Conventional Group	χ^2 Value	P Value
APACHE II≥25 scores (n=65/68)	10 (15.4)	25 (36.7)	8.72	0.003
APACHE II＜25 scores (n=48/45)	2 (5.8)	7 (15.2)	4.12	0.043

3.5 Analysis of the Core Roles of Clinical Pharmacists in MDT

In the MDT group, the intervention measures of clinical pharmacists mainly included: (1) Optimization of antimicrobial selection (100% of cases): Based on susceptibility results and PK/PD principles, avoid selecting intermediate or potentially drug-resistant drugs, and prioritize regimens with synergistic effects (e.g., tigecycline + cefoperazone sulbactam); (2) Individualized dose adjustment (92.9% of cases): Predict blood drug concentrations with the aid of AI models, and adjust doses for patients with hepatic and renal insufficiency or obesity (e.g., vancomycin loading dose adjusted according to weight and renal function); ③ Adverse reaction monitoring and management (6.2% of cases): Timely detect and manage renal injury and gastrointestinal reactions to avoid treatment interruption; ④ AMS recommendations (89.4% of cases): Optimize treatment courses (e.g., shorten the course of bloodstream infection from 14 days to 10-12 days) and de-escalate therapy (e.g., switch from intravenous to oral administration after the condition is stable).

4 Discussion

4.1 Core Mechanisms of MDT Model Improving XDR Infection Outcomes

4.1.1 Multidisciplinary collaboration breaks through single-discipline limitations

The complexity of XDR infections requires multi-dimensional professional support: infectious disease physicians accurately diagnose infection foci and grade the condition, microbiology technicians rapidly provide susceptibility and drug resistance mechanism data, clinical pharmacists optimize antimicrobial regimens, and intensive care physicians ensure organ function support.[4] In the traditional single-discipline model, physicians often lack professional knowledge of PK/PD and awareness of drug resistance trends, leading to inappropriate drug selection (e.g., selecting cephalosporins ineffective against CRE) or unreasonable doses (e.g., insufficient tigecycline dose leading to treatment failure). In this study, the appropriate rate of antimicrobial use in the

MDT group reached 94.7%, significantly higher than 67.3% in the conventional group, confirming the improvement of treatment rationality by multidisciplinary collaboration [5].

4.1.2 Precise antimicrobial therapy led by clinical pharmacists

The core value of clinical pharmacists is reflected in "precision" and "whole-course": ① Drug selection based on PK/PD principles: For CRE infections, prioritize drugs with high fT＞MIC target attainment rates (tigecycline, polymyxin) and formulate synergistic regimens; ② AI-assisted dose optimization: Predict peak and trough blood drug concentrations by integrating patient physiological parameters and drug metabolism characteristics, avoiding sub-therapeutic concentrations or toxic reactions caused by "one-size-fits-all" doses. In this study, the incidence of adverse reactions in the MDT group was only 6.2%, significantly lower than 18.6% in the conventional group; ③ Whole-course treatment monitoring: Dynamically evaluate clinical symptoms, laboratory indicators and bacterial eradication, adjust regimens in a timely manner (e.g., replace drugs when treatment is ineffective at 48-72 hours) to avoid delayed treatment opportunities [6].

4.1.3 Dual value of AMS in drug resistance control and cost optimization

AMS led by clinical pharmacists is an important part of the MDT model: ① Drug resistance control: Reduce the selection pressure of drug-resistant bacteria through rational drug selection, optimized treatment courses and avoiding unnecessary broad-spectrum antimicrobials. In this study, the incidence of XDR bacteria in the department of the MDT group decreased by 18.7% compared with before (unpublished internal data); ② Cost optimization: Prioritize cost-effective drugs (e.g., domestic tigecycline instead of imported drugs), shorten treatment courses and reduce additional treatment costs caused by adverse reactions, ultimately achieving a 32.6% saving in antimicrobial costs and a 28.9% saving in total medical costs, which is in line with the core demand of "improving quality and reducing costs" in global medical care [7].

4.2 Clinical Implications of Subgroup Analyses

4.2.1 Adaptability to different XDR bacterial infections

This study shows that the MDT model is effective against major XDR bacterial infections such as CRE, MRSA and VRE, especially for CRE infections with the most significant benefit (23.5% reduction in mortality). CRE carries carbapenemases (e.g., KPC, NDM) with very few treatment options, and the mortality rate under the traditional model is as high as 35% or more. The MDT team significantly improves the treatment success rate through drug resistance gene detection results provided by the microbiology department and synergistic treatment regimens formulated by clinical pharmacists, proving the effectiveness of this model for highly lethal XDR bacterial infections [8].

4.2.2 Special value for critically ill patients

Critically ill patients (APACHE II≥25 scores) have extremely high mortality from XDR infections due to low immune function, insufficient organ function and rapid infection spread. In this study, the mortality of critically ill patients in the MDT group decreased by 21.3%, significantly higher than the 9.4% of non-critically ill patients. The reasons are: ① The MDT team initiates treatment rapidly (average initiation time shortened by 8 hours) to avoid infection progression; ② Clinical pharmacists adjust doses for patients with organ insufficiency (e.g., renal failure) to avoid drug accumulation toxicity; ③ Multidisciplinary collaboration ensures organ function support and wins time for anti-infective treatment. This result suggests that critically ill patients with XDR infections should be the priority population for the MDT model [9].

4.3 Innovations and International Promotion Value

4.3.1 Technological innovation: integrated application of ai and pk/pd

This study integrates the AI drug concentration prediction model into the MDT workflow. Through machine learning algorithms integrating 12 parameters such as patient age, weight, hepatic and renal function and combined medications, the blood drug concentrations of vancomycin, tigecycline and other drugs are predicted with a prediction accuracy of 92.3%, providing a precise tool for clinical pharmacists to formulate individualized regimens. Compared with traditional empirical dose adjustment, AI-assisted optimization significantly improves

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the therapeutic concentration target attainment rate (89.7% vs 62.3%) and reduces the risk of adverse reactions, which is in line with the development trend of international precision medicine [10].

4.3.2 Model innovation: standardized MDT workflow

This study established a standardized MDT workflow of "24-hour initiation - regular consultation - whole-course monitoring - AMS feedback", clarifying the responsibilities of each discipline and improving collaboration efficiency. This workflow is highly replicable, especially suitable for resource-limited areas — through remote consultation to integrate resources of infectious disease specialists and clinical pharmacists from higher-level hospitals, primary hospitals can quickly carry out MDT treatment to solve the problem of insufficient XDR infection treatment capacity at the grassroots level, which has important global public health value.

4.4 Limitations and Future Prospects

This study is a single-center retrospective study with certain limitations: ① The retrospective design may have selection bias, which needs to be further verified by multi-center prospective RCT; ② Long-term drug resistance changes (e.g., 1-year recurrence rate of XDR bacteria) are not evaluated, requiring long-term follow-up studies; ③ The external validation of the AI model is insufficient, requiring an expanded sample size to optimize the algorithm.

Future research directions: ① Carry out multi-center prospective studies to verify the applicability of the MDT model in different regions and different levels of hospitals; ② Optimize the AI drug concentration prediction model, include more parameters (e.g., gene polymorphism) to improve prediction accuracy; ③ Explore the integrated application of the MDT model and rapid diagnostic technologies (e.g., metagenomic next-generation sequencing mNGS) to further shorten treatment initiation time; ④ Establish a global MDT collaboration network for XDR infections to promote experience sharing and technology promotion.

4.5 Comparison and Advantages with International Research

Compared with similar international studies (e.g., the MDT study for CRE infection published in *Lancet Infectious Diseases* in 2023), this study has three major advantages: ① Larger sample size (226 cases vs 158 cases), more comprehensive subgroup analyses and more reliable conclusions; ② The first integration of AI drug concentration prediction models into MDT practice to improve treatment accuracy; ③ Systematic evaluation of health economic benefits to provide a basis for the optimal allocation of global medical resources. The results of this study are consistent with international studies, both confirming that the MDT model involving clinical pharmacists can significantly improve the outcomes of XDR infections, further strengthening the international promotion value of this model.

5 Conclusion

The multidisciplinary team (MDT) model involving clinical pharmacists significantly improves the clinical cure rate and bacterial eradication rate of patients with XDR infections, reduces 30-day mortality and the incidence of adverse reactions, shortens hospital stay, saves medical costs and delays the development of drug resistance through multidisciplinary collaboration, precise antimicrobial therapy and systematic antimicrobial stewardship. This model has a scientific workflow, clear disciplinary responsibilities and significant comprehensive benefits, especially suitable for critically ill patients and highly lethal XDR bacterial infections. The innovatively integrated AI-assisted dose optimization technology further improves treatment accuracy.

As a feasible, efficient and replicable treatment model, it is not only suitable for tertiary hospitals, but also can be promoted to primary hospitals and resource-limited areas through remote collaboration, providing a practical plan for global XDR infection prevention and control. In the future, multi-center prospective studies are needed to further verify its long-term efficacy and drug resistance control effect, promote the standardized application of this model globally, and contribute to addressing the global antimicrobial resistance crisis.

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