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RESEARCH ARTICLE

Cost-benefit analysis of pharmacist early active consultation in patients with multidrug-resistant bacteria in China

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Abstract

Background Although Pharmacist Early Active Consultation (PEAC) has demonstrated clinical benefits in patients with multidrug-resistant organisms (MDROs), its cost-effectiveness in China remains insufficiently studied.

Aim This study aimed to evaluate the cost-effectiveness of PEAC in patients with MDROs from the perspective of the Chinese healthcare system.

Method A historically controlled study was conducted on 100 MDRO-infected patients, including 37 who received PEAC and 63 who did not. The effective treatment rate and duration of the symptoms were assessed. A decision tree model was developed using model inputs derived from the study. The primary endpoints included incremental cost per MDRO treatment and incremental cost-effectiveness ratio (ICER). Uncertainty was evaluated using one-way and probabilistic sensitivity analysis.

Results The effective treatment rate increased to 89.1% in the PEAC group compared with 62.1% in the no-consultation group. Patients in the PEAC group experienced a 2.1-day shorter duration of symptoms than those without consultation (15.5 days vs. 17.6 days, $P = 0.04$). The base case analysis estimated that the PEAC group gained 0.189 quality-adjusted life years (QALYs) at a cost of $18,209.7, while the no-consultation group gained 0.177 QALYs at a cost of $23,831.1. The PEAC group was more cost-effective, yielding an ICER of − $475,499.0 per QALY gained. Probabilistic sensitivity analysis indicated that PEAC was cost-effective in 60.1% of cases, with costs remaining below the willingness-to-pay (WTP) threshold, supporting PEAC as a cost-effective strategy for managing MDRO infections.

Conclusion Pharmacist Early Active Consultation was a more cost-effective strategy than no consultation for treating MDRO infections in patients in China.

Keywords Cost-effectiveness · Decision-tree model · Infection disease · Multidrug-resistant organism · Pharmacist early active consultation

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Impact statements

- Pharmacist Early Active Consultation (PEAC) plays a critical role in the timely and effective management of multidrug-resistant organism (MDRO) infections, accelerates patient recovery, and significantly improves clinical outcomes.
- Early pharmacist intervention fosters a shift toward patient-centered pharmacy services, reinforcing the expanded role of pharmacists in the management of infectious diseases and broader healthcare delivery.
- Recognized as a cost-effective strategy, PEAC has the potential to influence healthcare policies and drive reforms in medical service pricing within China's healthcare system.

Introduction

Multidrug-resistant organisms (MDROs) pose a significant global health challenge, contributing to approximately 4.95 million deaths annually owing to antimicrobial-resistant bacteria [1]. The economic burden associated with MDROs continues to rise, encompassing increased hospital expenditures, caregiver costs, and productivity losses due to premature mortality [2, 3]. The emergence and proliferation of MDROs are primarily attributed to the excessive and inappropriate use of antibiotics [4]. Moreover, delays in the administration of appropriate antimicrobial therapy to infected patients present a major challenge in managing MDRO-related infections, further complicating patient outcomes [5, 6]. Clinical pharmacists play a crucial role in antimicrobial stewardship by optimizing treatment strategies for drug-resistant infections and reducing mortality. However, pharmacist consultations are often initiated only at the physician's request, which can lead to treatment delays or therapeutic failure [7, 8].

To address this issue, our hospital has implemented a Pharmacist Early Active Consultation (PEAC) program, a proactive pharmacy consultation model led by clinical pharmacists. First, the hospital system automatically notifies clinical pharmacists of positive MDRO laboratory reports, prompting them to initiate a consultation within 24 h. Second, pharmacists assess patient severity using the National Early Warning Score 2 (NEWS2) [9, 10], interpret MDRO reports with consideration of sample details, and formulate individualized antimicrobial regimens. Lastly, pharmacists verify treatment plans, monitor therapeutic responses, educate patients, and provide follow-up care for up to 90 days after discharge. This proactive consultation approach enhances timely and effective antimicrobial management and ultimately improves patient outcomes. Our previous study demonstrated that PEAC significantly reduced 30-day all-cause mortality in MDRO-infected patients [11]. However, the economic impact of this intervention remains unclear.

Existing literature supports the cost-effectiveness of pharmacist-led interventions, such as medication reviews, reconciliation, deprescribing, and therapy de-escalation, particularly in chronic disease management [12–14]. However, few studies have focused on the economic value of pharmacist-driven interventions for infectious disease management. While numerous studies have highlighted the cost-effectiveness of antimicrobial stewardship programs, few have specifically examined the economic contributions of pharmacists [15, 16]. Notably, previous research assessing the economic impact of pharmacist involvement in antimicrobial therapy has predominantly focused on drug costs while overlooking other critical factors such as pharmacist salaries and the overall implementation costs of these interventions [17, 18]. No study has evaluated the cost-effectiveness of pharmacists' involvement in MDRO management. Given the constraints on healthcare budgets and workforce availability, assessing the economic value of PEAC as a novel service strategy for public payers is imperative.

Aim

This study aimed to evaluate the cost-effectiveness of PEAC in patients with MDROs from the perspective of the Chinese healthcare system.

Ethics approval

This study was approved by the Medical Ethics Committee of the Third Affiliated Hospital of Chongqing Medical University (Approval No. 2018-16, June 22, 2018).

Method

Model population

The PEAC program was implemented at the Third Affiliated Hospital of Chongqing Medical University in July, 2019. This hospital is a 1350-bed tertiary care teaching hospital in China with approximately 40,000 annual admissions. All participating clinical pharmacists obtained training certificates from the National Health Commission.

Patients diagnosed with MDROs who underwent the PEAC program between July 2019 and June 2020 comprised the consultation group. Patients diagnosed with MDROs between July 2018 and June 2019 who did not undergo the

PEAC program comprised the no-consultation group. This study focused on four major MDROs: carbapenem-resistant *Acinetobacter baumannii* (CRAB), carbapenem-resistant *Pseudomonas aeruginosa* (CRPA), carbapenem-resistant *Enterobacterales* (CREs), and methicillin-resistant *Staphylococcus aureus* (MRSA). Bacterial resistance was assessed using the minimum inhibitory concentration (MIC) method. Patients with cultures positive for any of these MDROs were included in the study.

Patients were excluded if they met any of the following criteria: (1) age < 18 years; (2) discharged, deceased, or transitioned to palliative care within three days of receiving a positive MDRO report; (3) belonged to the no-consultation group but received a clinical pharmacist consultation within 24 h for recuperation purposes; (4) belonged to the no-consultation group but received a consultation from an Antimicrobial Stewardship (AMS) team within 24 h; (5) belonged to the PEAC group but did not initiate the consultation within 24 h of receiving a positive MDRO result; or (6) had incomplete clinical outcome evaluations within the first 90 days after receiving a positive MDRO result. Supplemental Table 1 presents the baseline patient characteristics.

Sample size calculation

We estimated that the PEAC group required a minimum sample size of 36 to achieve 80% power to detect an increase in clinical effectiveness from 60 to 80%, with a two-sided alpha level of 5%. The observed clinical effectiveness rate in the intention-to-treat population (which included all enrolled patients) was compared with a prespecified historical control value of 60%, based on preliminary studies with small sample sizes. The comparison was conducted using an exact binomial test [19, 20]. The expected clinical effectiveness rate of 80% in the PEAC group was derived from relevant literature [21].

Model structure

A decision-tree model was constructed using TreeAge 2022 (TreeAge Software, Williamstown, MA) to evaluate the cost-effectiveness of the PEAC program compared with standard care without consultation in patients with MDROs. In this model, patients diagnosed with MDROs had two possible pathways: receiving PEAC or not receiving consultation. These two options are represented as separate branches that originate from the initial decision node. Terminal nodes indicate whether the treatment outcome was effective or ineffective.

Effective treatment was defined as a sustained improvement in infection-related symptoms, reduction in infection markers (e.g., white blood cell count, neutrophil ratio, procalcitonin), normalization of body temperature, and improved ventilation status [18, 22]. Conversely, ineffective treatment was characterized by no improvement or worsening of these clinical indicators. The structure of the decision tree model is shown in Supplemental Fig. 1.

Model input

The effective and ineffective treatment costs were identified in the two study groups. As the cost-effectiveness analysis of PPEAC was conducted from the healthcare provider's perspective in China, cost calculations were based solely on direct medical costs. For the no-consultation group, direct medical costs included material fees, catheterization fees, intensive care unit (ICU) and general ward stays, mechanical ventilation, and infection therapy expenses. In contrast, for the PEAC group, these costs were supplemented by the costs of clinical pharmacist services. The pharmacist's service fee per patient was estimated by multiplying the median hourly wage of $5.19 by the total time spent on each patient. This wage reflects the midpoint of the reported hourly salaries for clinical pharmacists in China, which range from $4.10 to $6.47 [23]. The total time spent per patient was estimated based on daily one-hour consultations from the date of MDRO-positive reporting to hospital discharge [24]. All costs originally recorded in the local currency were converted to US dollars (USD) at a mean 2021 exchange rate of 1 USD = 7.2532 RMB [25].

The probability of effective treatment (effectiveness rate) for both the PEAC and no-consultation groups was determined in this study. Quality-adjusted life-years (QALYs) were calculated by multiplying utility values (ranging from 0 to 1, representing quality of life) by the time spent in a given health state, typically expressed in years or fractions of a year. These utility values were derived from published studies that matched the infection profiles of MDRO-related diseases [15, 26–29]. The time to cure (duration of symptoms) in each group was determined in our study. The decision model adopted a 90-day follow-up period from the date of a positive MDRO notification. To maximize patient inclusion, the model applied day 90 sustained cure rates from Guery et al.'s study [30]. As the time horizon was less than one year, discounting was not applied. The input parameters of the model are presented in Table 1.

Base case analysis

The primary outcomes of this economic evaluation were the incremental cost per effectively treated MDRO infection and incremental cost-effectiveness ratio (ICER). ICER was calculated by dividing the difference in total accrued

Table 1 Medical costs and clinical outcomes based on the decision tree

Parameter	Base value	Range		Distribution	Source
		Low	High		
Costs (US dollars)					
Cost of patients treated with PEAC effectively	18006.8	761.3	61860.5	Gamma	–
Cost of patients treated with PEAC ineffectively	18644.1	9726.4	32602.9	Gamma	–
Cost of patients treated with Non-PEAC effectively	20794.6	392.6	87133.26	Gamma	–
Cost of patients treated with Non-PEAC ineffectively	28785.3	377.5	89692.4	Gamma	–
Cost of pharmacist	133.4	100.9	159.3	Gamma	–
Probabilities (%)					–
Effective rate of PEAC	89.1	80.1	98.0	Beta	–
Effective rate of Non-PEAC group	62.1	55.9	68.1	Beta	–
Duration of symptoms(d)					
Duration of symptoms in PEAC	15.5	4	47	Gamma	–
Duration of symptoms in Non-PEAC	17.6	5	75	Gamma	–
Utility					
Baseline utility (SD)	0.82	0.41	0.76	Beta	[15, 27–30]
Disease utility (SD)	0.62	0.8	0.88	Beta	[15, 27–30]

PEAC, pharmacist early active consultation; Non-PEAC, without pharmacist early active consultation

costs (incremental cost) by the difference in the effective treatment rate (incremental effectiveness rate). Additionally, ICER was assessed using incremental costs per incremental QALY gained.

To determine cost-effectiveness, the analysis adopted the willingness-to-pay (WTP) threshold recommended by the World Health Organization (WHO), which is set at three times the per capita Gross Domestic Product (GDP) of the respective country. Based on China's 2021 GDP of US$ 11,167.48, the WTP threshold was defined accordingly [25].

Sensitivity analysis

A one-way sensitivity analysis was conducted to assess the impact of parameter uncertainty on the model outcomes. Parameter ranges were derived from the same sources as base values or were assumed to fall within 95% confidence intervals [31]. Specifically, the clinical effectiveness probability was ± 10% of the baseline values. The results of the one-way sensitivity analysis are presented as a tornado diagram.

A probabilistic sensitivity analysis (PSA) was performed using 10,000 Monte Carlo simulations to further evaluate the robustness of the model results. In the PSA, probabilities, utilities, and population characteristics were assumed to follow beta distributions, whereas treatment costs, symptom duration, and pharmacist service costs were modeled using gamma distributions [31]. The PSA results are shown as a scatter plot.

Statistical analysis

Statistical analyses were performed using SPSS version 17 (SPSS, Chicago, IL, USA). Baseline characteristics were compared between the two groups using the chi-squared test to confirm the absence of significant baseline differences. Descriptive statistics were presented as mean ± standard deviation (SD). Statistical significance was set at $p < 0.05$.

Results

Effect of pharmacist consultation on clinical effectiveness

Figure 1 shows the flow chart of patient enrollment, with 37 and 63 patients in the PEAC and non-PEAC groups, respectively.

The implementation of PEAC significantly increased the consultation rate for MDRO infections, from 30.0% before PEAC to 93.3% after PEAC. In terms of clinical effectiveness, a higher proportion of patients in the PEAC group experienced either clinical symptom improvement or complete recovery than those in the no-consultation group. Specifically, 33 patients (89.1%) in the PEAC group achieved clinical effectiveness compared with 39 patients (62.1%) in the no-consultation group ($P = 0.01$). Furthermore, the duration of symptoms was significantly shorter in the PEAC group, with a mean reduction of 2.1 days compared with the no-consultation group (15.5 days vs. 17.6 days, $P = 0.04$).

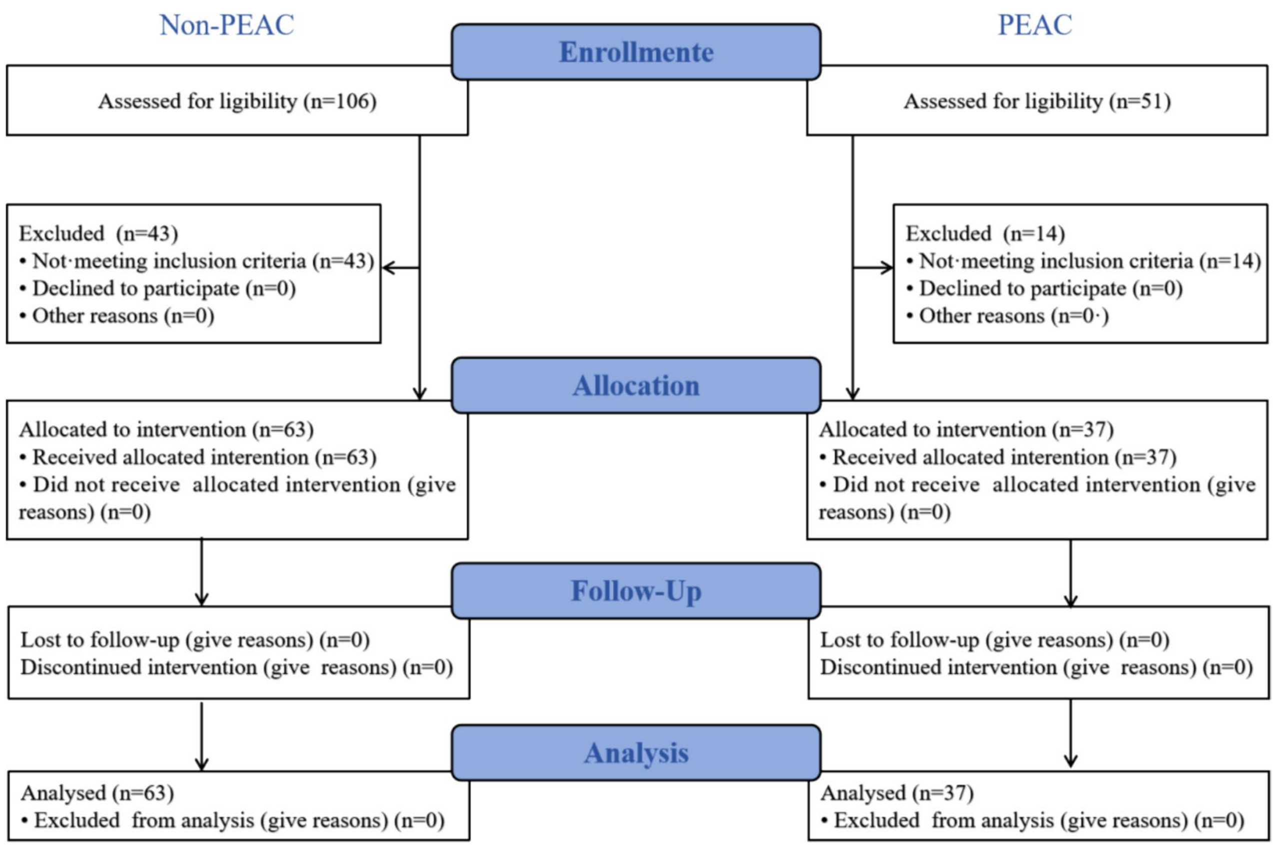

Fig. 1 Flowchart showing patient enrollment. PEAC, pharmacist early active consultation; non-PEAC, without pharmacist early active consultation

Table 2 Results of the cost-effectiveness analysis

Outcomes	Non-PEAC	PEAC
Cost ($)	23831.1	18209.7
Incremental cost ($)	ND	−5621.4
Probability of MDR infection treated effectively	0.62	0.89
Difference (probability of MDR infection treated effectively)	ND	0.27
Cost per infection avoided ($)	–	−20820.0[a]
Effectiveness (QALYs)	0.177	0.189
Incremental effectiveness (QALYs)	–	0.012
ICER ($/QALYs)	–	−475499.0

[a]Calculated via the formula Incremental cost ($) ÷ Difference (probability of infection treated effectively)

PEAC, pharmacist early active consultation; non-PEAC, without pharmacist early active consultation; $, US dollar; ICER, incremental cost-effectiveness ratio; ND, not determined; WTP, willingness to pay

Base case analysis

The total costs, clinical outcomes, incremental costs, and incremental effectiveness are listed in Table 2. The model estimated that the total cost per patient was $18,209.7 for those who received PEAC, compared to $23,831.1 for patients in the no-consultation group, resulting in an incremental cost reduction of $5,621.4.

In terms of clinical effectiveness, PEAC led to an absolute increase of 27.0% in the effective treatment rate compared with the no-consultation group. The incremental cost per effectively treated MDRO patient was −$20,820.0, indicating that PEAC not only improved treatment outcomes, but also resulted in cost savings. From a quality-of-life perspective, the model estimated that patients who received PEAC gained 0.189 QALYs compared with 0.177 QALYs for those without consultation. This resulted in an incremental increase in effectiveness of 0.012 QALYs. The ICER was -$475,499.0 per additional QALY gained, further supporting the conclusion that PEAC is a highly cost-effective strategy for MDRO treatment.

Sensitivity analysis

The tornado diagram in Fig. 2 identifies 11 key factors that influence ICER. The most sensitive parameter was the cost of effectively treated patients in the PEAC group,

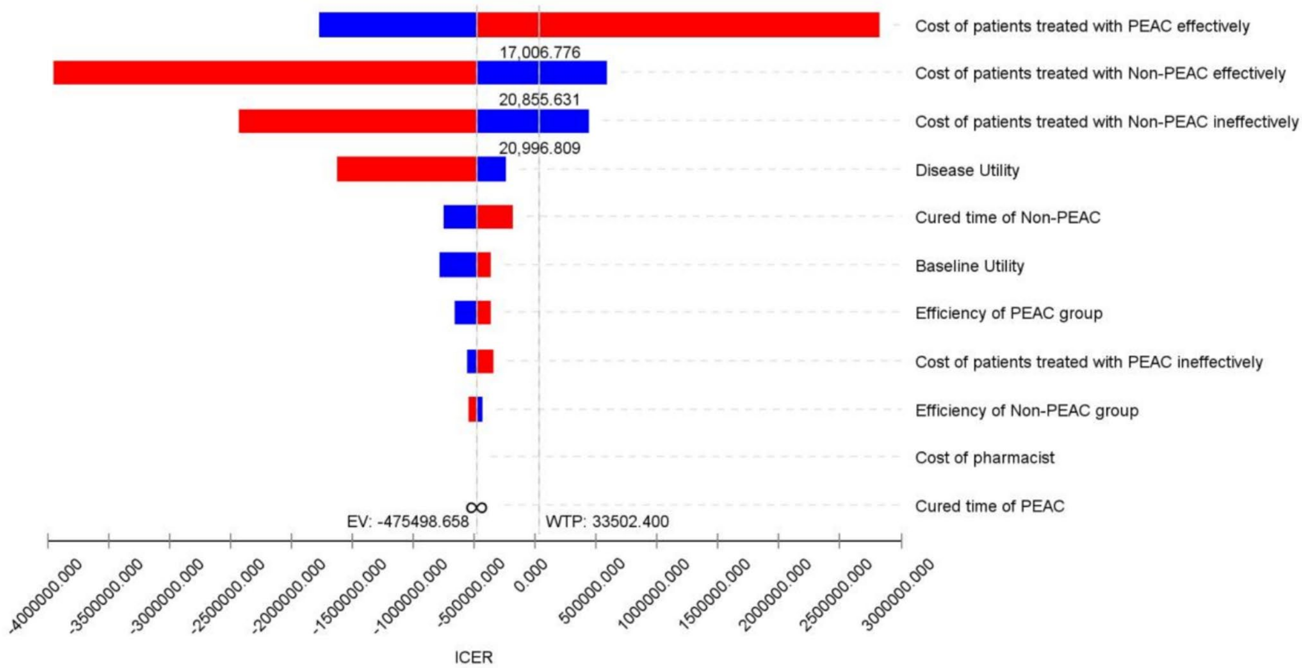

Fig. 2 Tornado diagram of one-way sensitivity analyses. PEAC, pharmacist early active consultation; non-PEAC, without pharmacist early active consultation; ICER, incremental cost-effectiveness ratio; WTP, willingness to pay

followed by the cost of effectively treated patients without consultation, and the cost of ineffectively treated patients in the no-consultation group.

The PEAC strategy would no longer be a more cost-effective option under the following conditions: (1) if the cost of effectively treated patients in the PEAC group exceeded \$17,006.8, (2) if the cost of effective treatment without consultation fell below \$20,855.6, or (3) if the cost of ineffective treatment in the no-consultation group dropped below \$20,996.8.

A scatter plot of incremental cost versus incremental effectiveness for the two groups is shown in Fig. 3. The results indicated that 61.2% of the simulations fell within the fourth quadrant and below the WTP threshold, demonstrating that PEAC was both more effective and less costly in most cases.

Figure 4 illustrates the cost-effectiveness probability of PEAC across various WTP thresholds. The findings show that PEAC remained cost-effective in over 61.0% of the scenarios at WTP thresholds ranging from \$0 to \$100,000. Moreover, the probability of PEAC being cost-effective increases nonlinearly with increasing WTP thresholds, reaching 63.8% at \$100,000. Importantly, in all cases, PEAC remained the optimal strategy, regardless of changes in WTP thresholds, reinforcing its economic and clinical advantages.

Discussion

To the best of our knowledge, this is the first study to perform a cost–benefit analysis using a decision tree model to evaluate the impact of timely PEAC in patients with MDROs in China. This study assessed various outcomes, including the clinical effectiveness and economic impact of PEAC in MDRO-infected patients. Our findings demonstrated that PEAC significantly increased both consultation and effective treatment rates among MDRO-infected patients. Pharmacist-led interventions have been shown to play a critical role in controlling MDRO infections [32].

More importantly, this study revealed that PEAC led to substantial cost savings, with the cost per MDRO infection avoided estimated at \$20,820.0. These cost savings directly associated with providing pharmacist consultations were primarily achieved through reduced expenses in several areas: material fees, catheterization costs, ICU and general ward admissions, the need for mechanical ventilation, and infection treatment costs. The decision-tree model further demonstrated that PEAC was more cost-effective than non-PEAC, yielding an ICER of − \$475,499.0 per additional QALY gained. Compared with standard care, PEAC has proven to be a highly cost-effective strategy for managing MDRO infections. These findings align with previous

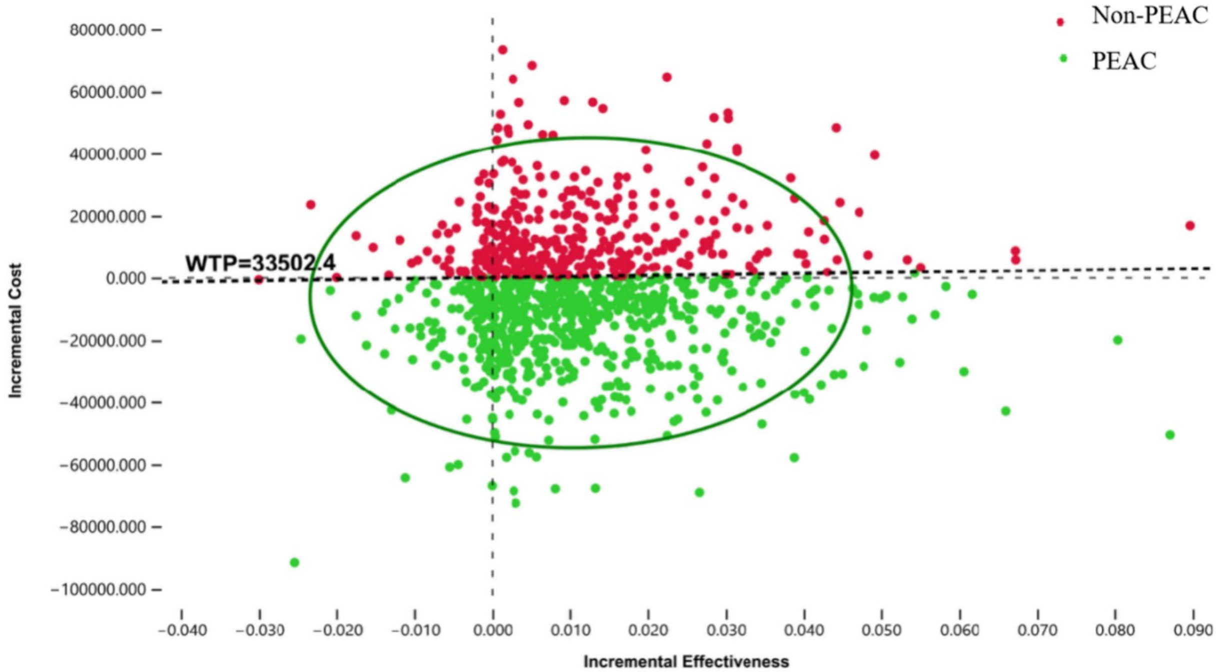

Fig. 3 Scatter plot of incremental cost and effectiveness of PEAC and non-PEAC. PEAC, pharmacist early active consultation; non-PEAC, without pharmacist early active consultation

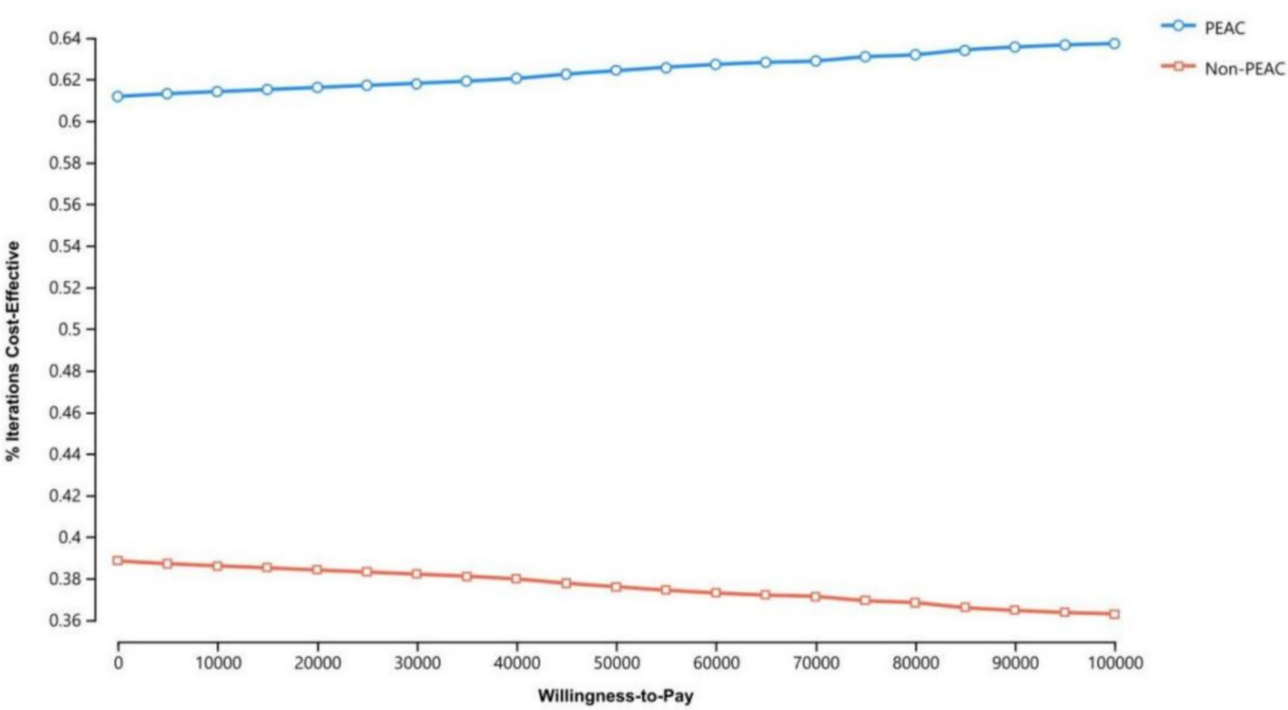

Fig. 4 Cost-effectiveness acceptability curve derived from probabilistic sensitivity analysis

research evaluating the cost-utility of pharmacist-led antimicrobial stewardship programs, particularly when combined with enhanced laboratory capacity [15].

This study was conducted from the perspective of the Chinese healthcare system and, therefore, included only direct medical costs rather than total healthcare expenditure.

If the analysis were conducted from the perspective of healthcare providers, the overall cost estimates might have underestimated [33]. For instance, the economic impact of pharmaceutical interventions is often associated with reductions in adverse drug reactions and drug-related problems, which were not accounted for in this analysis [34].

This study excluded costs related to readmissions and unplanned outpatient visits within 30 days post-discharge owing to data collection challenges in China. As patients seek care at different hospitals across various regions, tracking follow-up visits to the same institution is often infeasible. Another factor that influences cost estimates is medical insurance pricing, which varies significantly across provinces and cities in China. These regional variations may have contributed to the lower overall cost estimates. Clinical pharmacists' ability to conduct PEAC may vary based on their level of experience. Clinical pharmacists are categorized into senior advanced pharmacists (≥ five years of experience), advanced pharmacists (≥ three years), specialist pharmacists (≥ two years), and foundation pharmacists (< two years). Whether differences in pharmacists' seniority influence the economic evaluation of PEAC remains an area for further investigation. However, based on the sensitivity analysis conducted, it is unlikely that variations in pharmacist experience would alter overall cost-effectiveness. That is, PEAC would likely remain a more economical strategy, regardless of pharmacist seniority. The robustness of our findings, as demonstrated by sensitivity analysis, supports this inference.

Although most studies have demonstrated that PEAC significantly reduces mortality rates among patients with MDROs [35, 36], mortality was not included as a factor in our model. This decision was primarily due to limited utility data. Among the 45 MDRO patients in the PEAC group, three patients lacked clinical outcome evaluations within the first 90 days, and five patients achieved recovery within 3 days. Among the remaining 37 patients, 2 experienced 30-day all-cause mortality following a positive MDRO culture, making it challenging to obtain sufficient utility data. As a result, utility values were derived from the literature. Although health utility values may vary across countries owing to psychometric, economic, and sociocultural differences, our sensitivity analysis confirmed that the use of literature-based utility values did not impact the results.

In future research, additional clinical outcomes should be considered, including mortality rates, subgroup analyses based on infection sites, severity of infection, and specific MDRO strains. Expanding the scope of clinical and economic evaluations would further strengthen the robustness and applicability of pharmacist-led interventions for MDRO management. In our model, the primary outcome was the effective treatment rate for MDRO infections. Even assuming a 10% reduction in treatment efficacy, PEAC remained a more cost-effective strategy in the sensitivity analysis. Furthermore, our findings were reinforced by the cost-effectiveness acceptability curve, which demonstrated that PEAC consistently remained economically favorable across different WTP thresholds. The results of the one-way sensitivity analysis are also interpretable and relevant for health policymakers, further supporting the economic and clinical value of PEAC. These findings highlight the importance of integrating timely pharmacist-led consultations into clinical pathways for MDRO management, particularly as a cost-effective strategy in resource-limited health care settings.

This study had several limitations. First, the PEAC intervention was implemented hospital-wide in July 2018, necessitating an observational before and after study design. This temporal difference may have introduced a bias in the findings. Second, our study's small sample size, which may be subject to sampling randomness, could have introduced bias and limited the statistical power. Our sensitivity analyses, however, have confirmed the reliability of our primary outcomes despite these constraints. Chi-square tests indicated no significant baseline differences between the study groups, yet the small sample size may have limited statistical power, increasing the risk of a Type II error and potentially masking true differences. To thoroughly address these limitations, enhance the robustness of our findings, and consider their generalizability, future research should incorporate large-scale, multicenter, prospective studies to minimize potential biases and enhance the reliability and generalizability of the results.

In summary, within the constrained resource setting, we have developed an innovative and viable model for managing multidrug-resistant organism (MDRO) infections via early and proactive pharmacist interventions. This model is designed to not only optimize patient clinical outcomes but also economize on healthcare expenditures. Its adaptability and scalability make it suitable for diverse medical contexts. The research provides fresh insights into the significance of pharmacist interventions and the creation of strategies aimed at enhancing MDRO patient outcomes while conserving healthcare resources.

Conclusion

From the perspective of the Chinese healthcare system, Pharmacist Early Active Consultation is a more cost-effective strategy for managing multidrug-resistant organism infections than the absence of such a service.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s11096-025-01889-0.

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Conflicts of interest Authors declare no conflicts of interests.

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