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ORIGINAL RESEARCH

A Multidisciplinary-Based and Bundle Intervention for Controlling Carbapenem-Resistant Organisms in Neurosurgery

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Purpose: Carbapenem-resistant organisms (CROs) have been listed as the primary risk resistance bacteria due to their high detection rates and extensive drug resistance. Research on the effectiveness of CRO intervention programs in secondary hospitals is limited. This study aims to observe the effect of multidisciplinary-based and bundle interventions under PDCA (plan-do-check-act) cycle management on the control of CROs in neurosurgery.

Patients and Methods: We conducted a before-after study from January 2021 to December 2023, which was divided into pre-intervention phase and intervention phase. The surveillance analysis and event analysis were used to identify the key links and targeted pathogens of the intervention. PDCA cycle management tool was used to strengthen the bundle management of multidisciplinary collaboration. After one year of PDCA intervention, the process surveillance and outcome surveillance indicators of prevention and control measures from January 2023 to December 2023 were collected and compared with the pre-intervention phase (January 2021-December 2022).

Results: A total of 1809 patients were involved in our study. The 11 prevention and control measures were evaluated. After the implementation of PDCA cycle management, the measures including timely completion of multi-drug resistance prevention and control registration, and issuance of contact precaution orders, were significantly improved ($p < 0.05$). The total detection rate of CRO strains was 52.25%, which was significantly lower than 66.45% before intervention (RR = 0.786; 95% CI, 0.678–0.912; $p < 0.05$), and the incidence density of patients infected or colonized with CROs showed significant decrease from 18.75 per 1000 patient-days to 15.09 per 1000 patient-days (IRR = 0.563; 95% CI, 0.449–0.707; $p < 0.05$).

Conclusion: The multidisciplinary and bundle interventions based on PDCA cycle management tool had a good effect on the prevention and control of CROs in neurosurgery.

Keywords: PDCA, carbapenem-resistant organisms, neurosurgery, intervention

Introduction

The rapid spread of multidrug-resistant organisms (MDROs) in hospitals has become a global public health threat. At present, the drug resistance problem in China is more serious than that in some developed countries.[1] Among them, the most attention needs to be paid to carbapenem-resistant organisms (CROs), which have been listed as the primary risk resistance bacteria of WHO due to its high detection rate and extensive drug resistance.[2] It mainly includes carbapenem-resistant *Enterobacterales* (CRE), carbapenem-resistant *Acinetobacter baumannii* (CRAB) and carbapenem-resistant *Pseudomonas aeruginosa* (CRPA).[3,4] Carbapenem-resistant *Klebsiella pneumonia* (CRKP) and carbapenem-resistant *Escherichia coli* (CREC) were the main CRE.[5] CROs are among the most challenging antibiotic-resistant pathogens to emerge in the clinical setting. They spread rapidly in healthcare environments and can lead to significant outbreaks by contaminating the environment, equipment, and hands, particularly in institutions with limited infection prevention and control (IPC) resources.[4,6] Their extensive or pan-drug

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resistance results in very limited therapeutic options, causing high mortality rates in infected patients.[7] A meta-analysis suggested that mortality was significantly higher in CRKP patients (466/1093, 42.6%) than in those with carbapenem-susceptible *Klebsiella pneumoniae* (231/859, 26.9%).[8] Other studies have reported that the all-cause mortality rate for patients infected with CRE reaches 50%,[9] whereas the mortality rate for patients with CRO blood infections was as high as 56.3%,[10] and 76.6%.[11]

As medical science continues to make breakthroughs in extending human longevity, the aging of Shanghai's population is becoming increasingly prominent. Within the city's current three-tier healthcare system, secondary hospitals primarily treat elderly individuals with complex underlying diseases, frequent hospitalizations, transfers between various healthcare institutions, long-term exposure to antibiotics, and invasive procedures, thus becoming a high-risk group for CRO infection or colonization.[12] The results of the previous infection control professional (ICP) surveillance work revealed that the detection rates for CRKP and CREC at the hospital in 2021 surpassed those reported by CHINET (China Antimicrobial Surveillance Network) (CRKP: 42.24% vs 24.4%, CREC: 5.30% vs 2.0%). Consequently, it is imperative to implement effective interventions to control CROs in this category of hospitals. CRO infection prevention and control is complex and involves multiple disciplines and departments. Thus, it is difficult to achieve control with one single intervention strategy. Current CRO intervention studies were adopting a bundle strategy. For instance, in epidemic settings, hand hygiene, contact precautions, active screening, isolation and environmental cleaning are strongly recommended for all CROs, and education, timely notification, communication, antimicrobial stewardship, active surveillance are recommended in CDC CRE toolkit.[4] Previous studies have confirmed that the bundled management of multidisciplinary collaboration has a positive practical effect on the prevention of MDROs infection in hospitals.[13–17] There were some differences in the intervention combination elements selected by each institution based on their actual situations.

In recent years, studies on MDROs prevention and control interventions have involved a variety of management tools, including PDCA cycle management.[18] PDCA cycle management method includes four steps: Plan, Do, Check, and Act.[19] The management tool has been widely used in the medical field.[20] Some studies have shown that the management method can effectively reduce the incidence of nosocomial infection and improve the ability of medical quality management.[21–25] A recent meta-analysis by Chinese scholars indicated that the majority of intervention studies involving CROs in China were conducted in large tertiary hospitals (20/21, 95.2%), with few related studies reported in secondary hospitals.[26] Building upon the data from our previous research,[27] we conducted a problem-oriented prevention and control practice based on PDCA cycle management in neurosurgery at a secondary hospital in Shanghai, China.

Patients and Methods

Study Design

The study was conducted in neurosurgery of Shidong Hospital, a secondary general teaching hospital located in Shanghai, China. The neurosurgery department owned 5 rooms, 20 beds, 4 clinicians and 10 permanent nursing staff. The hospital has a dedicated IPC team with a stable staff composition.

The study was divided into 2 phases: pre-intervention phase, from January 2021 to December 2022, and intervention phase, from January 2023 to December 2023. During the pre-intervention phase, we performed proactive and prospective surveillance, and investigated a suspected outbreak of CRKP infection occurred in neurosurgery in December 2021.[27] During the intervention phase, we implemented a multidisciplinary-based and bundle intervention by the PDCA cycle management.

Subjects

We included all patients admitted to the neurosurgery between January 2021 and December 2023. Patient data were collected from electronic medical records. In the clinical microbiology laboratory, species were identified using the automated VITEK 2 system (bioMérieux, Marcy l'Etoile, France). The antimicrobial susceptibility testing was also determined by VITEK 2 and breakpoints were applied according to the Clinical and Laboratory Standards Institute (CLSI).[28] The patients colonized or infected with CRO strains were as the objects of supervision. The duplicate strains and contaminated strains were removed. The privacy of all patients was fully protected and informed consent was waived. This study was approved by the ethical committee of Shidong Hospital (2023–057-01).

PDCA Details (Timeline Shown in FIGURE 1)

Plan

Analyze the Current Situation and Find Out the Problems

According to the surveillance statistics of ICP, the detection rates of CRAB, CRKP and CRPA were high in the hospital in 2021, and the neurosurgery was with the highest detection rate. Among them, the detection rates of CRAB, CRKP and CRPA were significantly higher than that of the hospital ($p < 0.05$), as shown in Supplementary Table 1.

Analyze the Influencing Factors Through Investigation of a Suspected Outbreak of CRKP Infection

A suspected outbreak of CRKP infection occurred in neurosurgery in December 2021.[27] The investigating analysis found that the suspected outbreak was closely related to the sink in the ward bathroom, possibly due to the environmental contamination of pathogens in patients with CRKP infection/colonization and the hand transmission by medical staffs, caregivers and accompanying family members. The deep causes of high detection rate of CROs in the neurosurgery were analyzed by fishbone diagram (Figure 2).

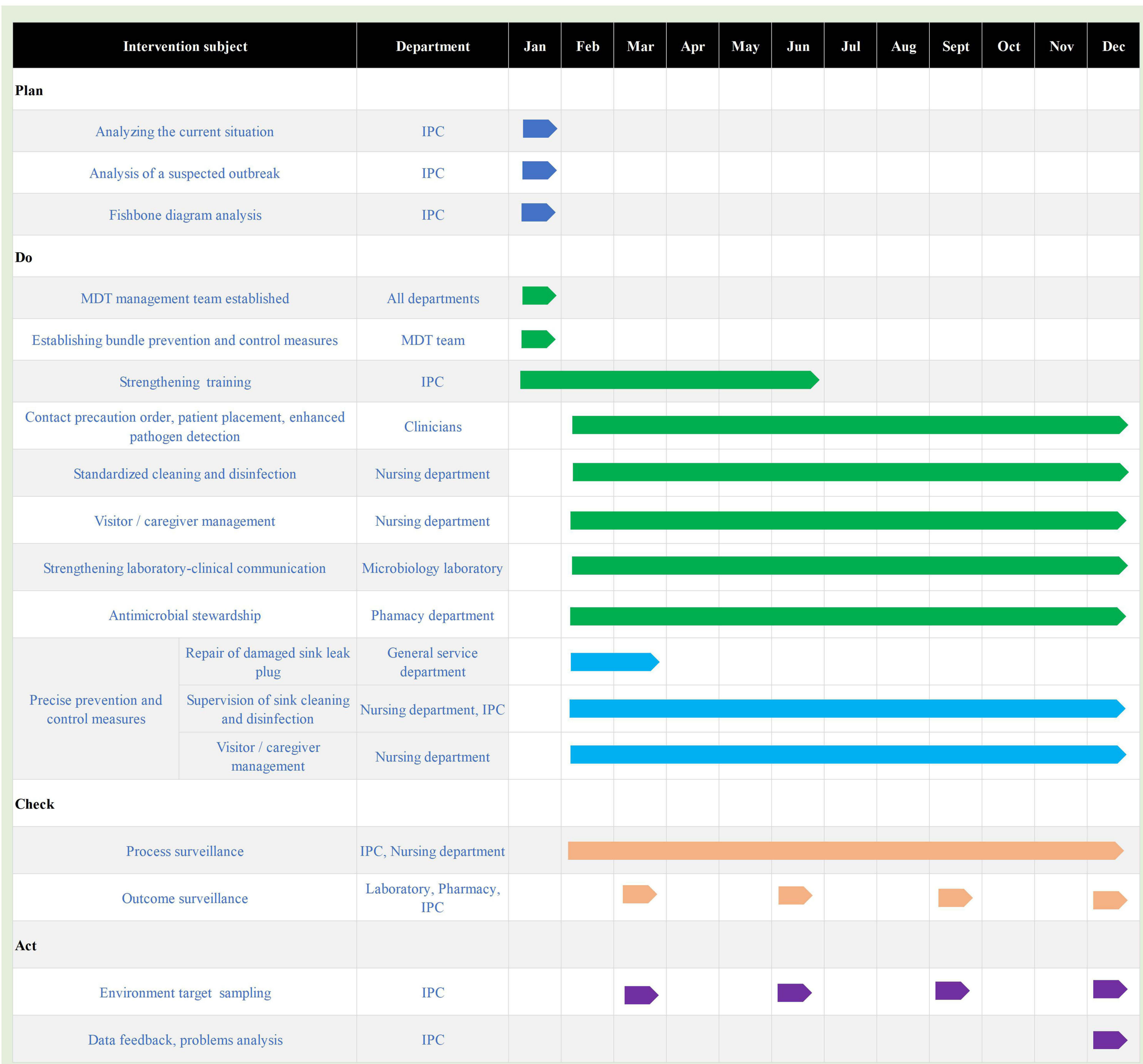

Figure 1 Interventions implementation timeline (Jan, 2023-Dec, 2023).
Abbreviations: MDT, multi-disciplinary team. IPC, infection prevention and control.

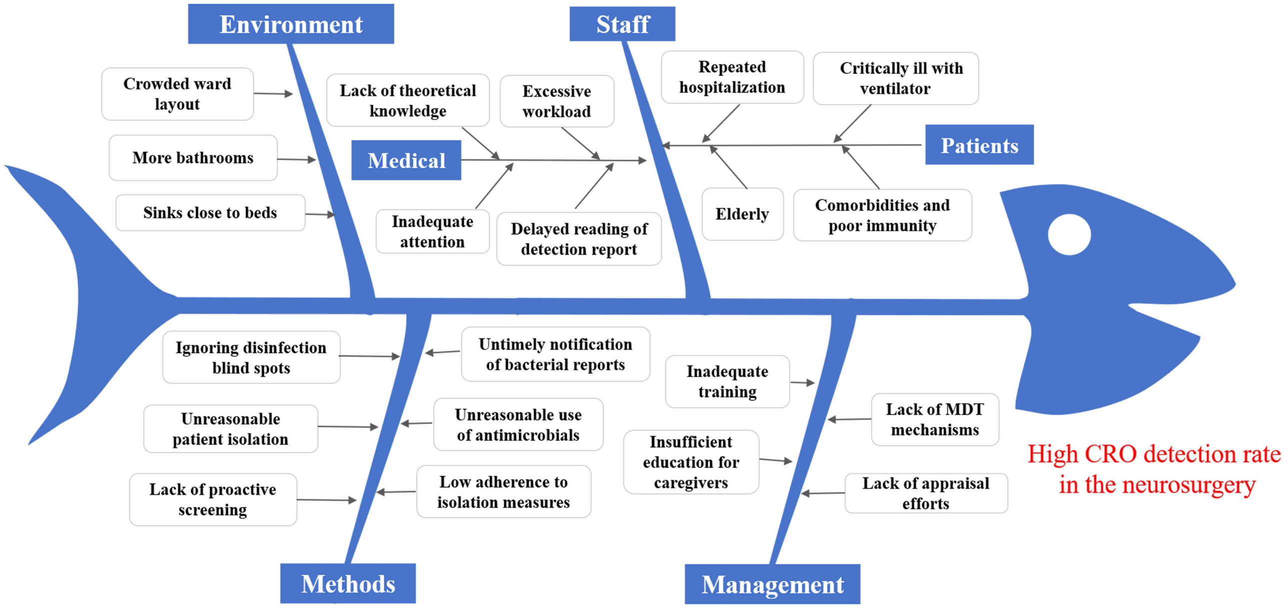

Figure 2 Cause analysis of high detection rate of CROs in neurosurgery by fishbone diagram.
Abbreviations: CROs, carbapenem-resistant organisms. MDT, multi-disciplinary team.

Do

Formulation of Multidisciplinary Collaborative Bundle Management Measures

CROs infection management is complicated and involves multiple disciplines and departments, so it is urgent to propose collaborative and bundle prevention and control plans in multi-disciplinary team (MDT). In 2023, a MDT management team was established under the unified leadership of the director in charge of hospital infection control, with the participation of department of IPC, neurosurgery, the clinical microbiology laboratory, nursing department, pharmacy department and other relevant departments.

MDROs are mainly transmitted through contact. Studies have shown that hand hygiene, environmental cleaning and disinfection, and medical staff training are very critical to prevent transmission, which help reduce the risk of nosocomial transmission of MDROs.[29–31] The department of IPC referred to accreditation regulation of control and prevention of healthcare associated infection in hospital[32] and technical guidelines for prevention and control of multidrug resistance organism healthcare-associated infection (Trial),[33] established bundle prevention and control measures, and developed the training plans about hospital infection knowledge. Regularly organized part-time staffs of infection control to conduct special training on prevention and control plan of CROs infection, early warning and disposal of nosocomial infection outbreak, disinfection and isolation, and medical waste management. Carried out personalized training for different personnel (clinicians, nurses, caregivers, and cleaners), and on-site assessment of the core content. Cooperated with other departments to find out the problems existing in the work in time, and proposed an improvement plan.

Neurosurgical clinicians implemented various measures, including active CRE screening, isolation and placement, and enhanced pathogen detection prior to antimicrobial therapy. For the reasonable placement of CRO infected/colonized patients, the clinicians timely issued isolation medical advice and tried not to arrange the room to share with susceptible patients such as endotracheal intubation/incision. The nursing department was mainly responsible for the supervision of the behavior of caregivers and cleaners, and implementation the management of hand hygiene, cleaning and disinfection. The clinical microbiology laboratory regularly carried out training for clinicians on correct collection and submission of microbial specimens, timely conducted culture, isolation and identification, and drug susceptibility experiments of the samples, and proactively informed the detected CRO results in the first time. It helped the physicians to issue quarantine orders as early as possible, and the head nurse supervised and managed the implementation of isolation measures in time. The pharmacy department was responsible for regular monitoring and analysis of bacterial drug resistance and early warning of antibiotic use. It reviewed and guided the indications for antibiotic treatment, the types and doses of medications, and reminded physicians to adjust medication regimens in a timely manner based on antimicrobial susceptibility results. This guidance aimed at promoting the clinical rational use of antibiotics and involved participation in consultations regarding the special antibiotics for difficult patients.

Precise Prevention and Control Measures to Strengthen Management

Guided by the analysis of the above suspected outbreak, CROs precise prevention and control management should be strengthened. After the Shanghai COVID-19 pandemic in 2022, the hospital's healthcare staff paid more attention to hand hygiene practices, the correct use of protective equipment and other preventive measures, which had a positive effect on the implementation of the project. Consequently, we possessed more energy to focus on other key aspects during the intervention phase. The cleaning and disinfection of the sink of the ward toilets, the implementation of contact precautions and isolation of patients and other personnel management should be taken as the key intervention directions.

The nursing department adopted intensive supervision to ensure that the daily cleaning and disinfection of the bathroom sink was in place, informed the general service department to repair the damaged sink leak plug, and urged the cleaners to soak the disinfectant for more than 30 min twice a day and clean the dirty supplies and appliances on the sink countertop. It was due to the fact that the neurosurgical patients mostly had accompanying family members or caregivers with large mobility, and most of them had no awareness and knowledge of the prevention and control of MDROs. Therefore, it was necessary to strengthen the management of accompanying family members or caregivers. The visitation should be limited for patients with CRO infection/colonization.

Check

During the intervention, the process surveillance and outcome surveillance indicators of prevention and control measures were collected.

Process Surveillance of Prevention and Control Measures

According to the technical guidelines for prevention and control of multidrug resistance organism healthcare-associated infection (Trial)[33] and Chinese experts' consensus on prevention and control of multidrug resistance organism healthcare-associated infection,[34] the prevention and control measures such as implementation of contact precaution measures were observed and monitored by ICP prospectively and the record data were aggregated by month, and results were feedback to departments.

Outcome Surveillance of Prevention and Control Measures

The study assessed two outcome measures: the CRO detection rates and the incidence density of patients infected or colonized with CROs. Data were calculated and analyzed for CRAB, CRKP, CRPA and CREC separately as follows:[35]

CRO detection rate = (number of cases of CRO strains detected in patients/total number of the particular type of bacteria detected in patients in the ward during the same period) × 100%.

For example: CRKP detection rate = (number of cases of CRKP strains detected in patients/total number of cases of *Klebsiella pneumoniae* detected in patients in the same ward during the same period) × 100%.

Act

The IPC reported the detection rates of CROs and the incidence rates to the neurosurgery department quarterly, and conducted CRO target bacteria sampling and testing for the ward environment and hands of medical staff every quarter, including high-frequency contact environment surfaces and medical equipment, such as bed rails, call buttons, bedside tables, monitors, infusion pumps, bed curtains, and door handles, and water environment such as sinks, mop cleaning places, and waste liquid dumping places. The sampling method refers to the regulation of disinfection technique in healthcare settings (WS/T 367–2012).[36] After the collection of environmental specimens, it was promptly sent to the clinical microbiology laboratory for CRO target bacteria detection and drug susceptibility analysis to analyze the distribution of pathogenic bacteria and evaluate the focus of follow-up cleaning and disinfection intervention. The results were timely feedback to the physician and head nurse, and the remaining problems of PDCA management were found to enter the next cycle for continuous improvement.

Statistical Analysis

Data analysis was performed using SPSS 22.0 statistical software (SPSS *Inc)*. The distribution of quantitative variables was tested. Normally and abnormally distributed quantitative variables are presented as the mean ± standard deviation (SD) and the median (25th–75th interquartile range (IQR)), respectively. The comparison between the groups was conducted using *t* test or Mann–Whitney *U*-test. The qualitative data were described by frequency and percentage. The comparison between the groups was conducted using the Chi-square test or Fisher's exact test. Relative risk (RR) ratios with 95% confidence intervals (CI) were calculated for comparison of detection rates at intervention period and pre-intervention. Poisson regression was used for calculating the incidence rate ratios (IRR) with 95% CI of patient CRO incidence density between periods. The $p < 0.05$ with two-tailed was considered to be statistically significant.

Results

General Condition

A total of 1809 patients were involved in our study, with 1026 patients in the pre-intervention phase and 783 patients in the intervention phase. The total patient-days amounted to 10984 and 7687, respectively. The patient characteristics are presented in Table 1. There were no significant differences in age, gender, primary diagnosis, consciousness on admission, patient underlying diseases and invasive procedures between both phases ($p > 0.05$).

Process Surveillance results

After one year of PDCA intervention, the implementation rate of several core prevention and control measures had been improved to a certain extent. Among these, the compliance rate for timely completion of MDRO registration increased from 37.61% to 55.38%, and the issuance rates of contact precaution orders and quarantine signs both rose from 41.28% to 61.61% ($p<0.05$). The informing rate of medical staff and detection records of drug-resistant bacteria have significantly improved ($p < 0.05$). The compliance rates of hand hygiene before and after medical staff operations were high in both stages (83.93% vs 78.90%, $p > 0.05$), and the completion rates of standardized cleaning and disinfection were similarly high in both stages (87.50% vs 82.57%, $p > 0.05$). The implementation rates of terminal disinfection were 100% in both stages. Although the caregivers' knowledge rate had improved to some extent, it was still low (32.14% vs 17.43%, $p < 0.05$), and further optimization of intervention measures was needed, as shown in Table 2.

Table 1 Comparison of Patient Baseline Characteristics

	Before Implementation (n = 1026)	After Implementation (n = 783)	*P* Value
Age, years (mean ± SD)	71.97 ± 14.07	71.03 ± 13.21	0.152
Male (%)	577 (56.23)	426 (54.40)	0.437
Primary diagnosis of admission			
Cerebrovascular disease (%)	725 (70.66)	539 (68.83)	0.401
Disorder of consciousness (%)	144 (14.04)	111 (14.18)	0.932
Emergency admission	632 (61.60)	493 (62.96)	0.553
Underlying diseases			
Hypertension	427 (41.62)	320 (40.87)	0.748
Cardiovascular diseases	62 (6.04)	48 (6.13)	0.939
Diabetes	202 (19.69)	225 (28.74)	0.055
Chronic respiratory diseases	10 (9.74)	11 (14.05)	0.400
Hypoproteinemia	3 (0.29)	2 (0.26)	0.882
Invasive procedures			
Urinary catheter	27 (2.63)	18 (2.30)	0.653
Central venous catheter	89 (8.67)	60 (7.66)	0.438
Mechanical ventilation	12 (1.17)	8 (1.02)	0.766
Surgery	106 (10.33)	87 (11.11)	0.595

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Table 2 Comparison of the Implementation of the 11 Prevention and Control Measures Before and After PDCA Cycle Management

Prevention and Control Measures	Before Implementation (n = 109)		After Implementation (n = 112)		χ^2	*P* Value
	Number of Actual Execution Cases	Percent of Pass (%)	Number of Actual Execution Cases	Percent of Pass (%)		
Timely completing the registration of MDRO prevention and control measures	41	37.61	62	55.38	6.988	0.008
Issuance of contact precaution orders	45	41.28	69	61.61	9.135	0.003
Hanging quarantine signs	45	41.28	69	61.61	9.135	0.003
Equipping with isolation clothing and quick hand disinfectant	44	40.37	67	59.82	8.363	0.004
Special use for medical devices	37	34.58	73	65.18	10.065	0.001
Medical staff was informed about the patient with MDRO infection / colonization	45	41.28	64	57.14	5.558	0.018
Medical staff shall perform hand hygiene before and after operation	86	78.90	94	83.93	0.925	0.336
Standardized cleaning and disinfecting around the bed unit	90	82.57	98	87.50	1.057	0.304
Escorts know about hand hygiene and item handling	19	17.43	36	32.14	6.396	0.011
The course of the disease has record of MDRO detection	38	34.86	59	52.68	7.120	0.008
Performing terminal disinfection	109	100	112	100	/	/

Note: /, not applicable.
Abbreviations: MDRO, multidrug-resistant organism.

Outcome Surveillance results

In the intervention phase, the total detection rate of CRO strains was 52.25%, which was lower than 66.45% before the intervention, and the difference was statistically significant (RR, 0.786; 95% CI, 0.678–0.912; $p < 0.05$). Among the targeted monitoring bacteria, the detection rate of CRKP decreased statistically from 81.15% to 49.40% ($p < 0.05$), as shown in Table 3.

Among the total patients included in the study, the incidence density of CROs isolates showed significant decrease from 18.75 per 1000 patient-days to 15.09 per 1000 patient-days (IRR, 0.563; 95% CI, 0.449–0.707; $p < 0.05$), especially for CRKP and CRAB with varying degrees of decline (Table 4).

Discussion

The core of hospital infection control is the epidemiological surveillance of nosocomial infection. Taking the dynamic monitoring results as the starting point, analyzing the reasons behind the data, taking the problems found as the orientation, and integrating the concept of accurate infection control are effective measures for the prevention and control of hospital infection. In a recent before-after study in China,[18] through a multidisciplinary collaborative model and process supervision, the spread of MDROs was effectively reduced. During the intervention, the implementation rate of various prevention and control measures increased, and the main outcome indicators were reflected in the downward trend of detection rates for CRKP and MRSA. However, the authors also pointed out that analyzing specific reasons and conducting more targeted MDROs precise prevention and control according to the characteristics of different

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Table 3 Comparison of CRO Strains Detected Before and After the Implementation of PDCA Cycle Management

CROs	Before Implementation (January 2021-December 2022)			After Implementation (January 2023-December 2023)			RR (95% CI)	*P* Value
	Total Number of the Particular Type of Bacteria	Number of CROs Detection	Detection Rate, %	Total Number of the Particular Type of Bacteria	Number of CROs Detection	Detection Rate, %		
CREC	13	1	7.69	12	0	0.00	/	0.327
CRKP	122	99	81.15	83	41	49.40	0.609 (0.482–0.769)	<0.001
CRAB	86	75	87.21	46	37	80.43	0.922 (0.783–1.087)	0.301
CRPA	89	31	34.83	81	38	46.91	1.347 (0.933–1.943)	0.109
Total	310	206	66.45	222	116	52.25	0.786 (0.678–0.912)	0.001

Abbreviations: CROs, carbapenem-resistant organisms; CREC, carbapenem-resistant Escherichia coli; CRKP, Carbapenem-resistant Klebsiella pneumonia; CRAB, carbapenem-resistant Acinetobacter baumannii; CRPA, carbapenem-resistant Pseudomonas aeruginosa. RR, relative risk. CI, confidence intervals. /, not applicable.

Table 4 Incidence Density of Patients Infected/Colonized With CROs Before and After Implementation

CROs	Before Implementation n (Incidence Density per 1000 Patient-Days)	After Implementation n (Incidence Density per 1000 Patient-Days)	IRR (95% CI)	*P* Value
CREC	1 (0.09)	0 (0.00)	/	/
CRKP	99 (9.01)	41 (5.33)	0.414 (0.288–0.596)	< 0.001
CRAB	75 (6.83)	37 (4.81)	0.493 (0.333–0.731)	< 0.001
CRPA	31 (2.82)	38 (4.94)	1.226 (0.763–1.970)	0.400
Total	206 (18.75)	116 (15.09)	0.563 (0.449–0.707)	< 0.001

Abbreviations: CROs, carbapenem-resistant organisms; CREC, carbapenem-resistant Escherichia coli; CRKP, Carbapenem-resistant Klebsiella pneumonia; CRAB, carbapenem-resistant Acinetobacter baumannii; CRPA, carbapenem-resistant Pseudomonas aeruginosa. IRR, incidence rate ratio. CI, confidence intervals. /, not applicable.

departments and links is the direction for future exploration. Our data from IPC surveillance and patient characteristics suggested that secondary hospitals may experience a higher prevalence of CRO epidemics compared to tertiary hospitals. The detection rates of CRAB, CRKP, and CRPA in neurosurgery were significantly higher than those in the hospital overall. This situation calls for the urgent implementation of intervention strategies in the department. In the past, the prevention and control of MDROs did not achieve good results despite repeated training in the hospital, mainly due to the lack of accurate risk assessment and excessive control measures without primary and secondary points. In this study, the precise prevention and control of hospital CROs was problem-oriented, and formulated key intervention measures to achieve the accurate infection control of key departments, key links and targeted pathogens, using PDCA management tools, strengthening the bundle management of multidisciplinary collaboration, and continuously tracking and evaluating the effect of prevention and control measures, which had a significant effect.

CROs are currently the global focus of MDROs, and prevention and control is a complex and lasting systematic work involving the collaboration of multiple disciplines and the whole-process prevention and control of each link. The CROs prevention and control measures in the implementation process of PDCA management require close cooperation among multiple departments to promote multidisciplinary cooperation with bundle management. In this hospital, upon analyzing the "Management" component in the fishbone diagram, we identified "Lack of MDT mechanisms" as a critical deficiency. This was reflected in the absence of timely communication and collaboration among laboratory professionals, clinicians, ICPs, and pharmacists. Most patients admitted to the neurosurgery are elderly and critically ill, and the insufficient proportion of medical care leads to an excessive workload. These unintervenable factors were part of the analytical composition of the fishbone under "Staff", thus contributing to the delay in checking the detection result reports for MDROs. Process surveillance data (Table 2) primarily indicates a low execution rate of contact precaution orders in the pre-intervention phase. Concurrently, other medical staff had a low awareness of CRO infected/colonized patients. So, the active cooperation of laboratory professionals is very important. Through clinical communication and training, providing timely feedback on testing results can assist doctors in issuing isolation medical orders promptly and implementing contact precaution measures. Process surveillance data indicated that the issuance rate of contact precaution orders and the knowledge rate of MDRO infection/colonization have effectively increased after intervention. Additionally, this assists the ICP in conducting supervision, thereby significantly reducing the risk of CRO transmission. Studies have shown that antimicrobial management has an important role in controlling bacterial resistance.[37,38] A pre- and post-intervention cohort study demonstrated that the implementation of an Antimicrobial Stewardship (AMS) program in a neurosurgical ICU resulted in a significantly lower prevalence of MDRO-positive patients in the AMS group compared to the pre-AMS group (18.48% vs 11.03%, $p = 0.001$), indicating a significant impact on *Klebsiella pneumoniae*.[39] The present study, which incorporates elements of pharmaceutical department intervention yields results consistent with it. During the implementation phase of our project, clinical pharmacists play a crucial role in reducing the inappropriate use of antimicrobials as part of the MDT working group. We have observed that the use of antimicrobial drugs, especially carbapenems, has been standardized during the intervention phase, leading to an effective reduction in the antibiotics use density (AUD) of carbapenems. These measures have made effective intervention from all dimensions of "Methods".

Regarding the "Environment" component analysis of the fishbone diagram, there were certain limitations due to hardware facilities. These included the cramped layout of the rooms, small bed spacing, and the presence of two bathrooms in each room, each equipped with a sink, with the bathrooms being in close proximity to the beds. The phenomenon of adding beds occurs during the peak season, and it is often difficult to achieve the reasonable placement of patients with drug-resistant bacteria and other patients with low immunity. The studies have shown that *Acinetobacter, Escherichia coli, Klebsiella*, and *Pseudomonas aeruginosa* among Gram-negative bacteria can survive in the environment for several months, and have high rate in the hospital environment.[34,40,41] In our previous suspected outbreak investigation,[27] CRKP detected in ward sink was consistent with the drug susceptibility spectrum of the isolated bacteria from patients. The sink around the bed may also become a major area for the spread of pathogens.[42] The toilet and the sink were ignored for disinfection in the past. In our intervention project, the cleaning and disinfection work of the toilet and the sink was included in key intervention part. We have conducted training and intensive supervision of nursing and cleaning staff, along with periodic environmental sampling by the ICP. These measures have contributed to the implementation of disinfection in previously overlooked areas.

At present, the existing problems mainly come from the excessive workload. The compliance with various prevention and control measures of medical staff, especially clinicians, is still not close to 100%. The implementation rate of contact precaution orders is the primary focus, similar to a previous study by Wang Y,[43] where the issuance rate was 33.12% of pre-intervention and increased to 75.88% of post-intervention. The two studies included both infected and colonized patients with an implementation rate significantly higher than the baseline. However, a very high level was not achieved in a short period. The hospital is currently in the construction of the new campus. Under the guidance of the department of IPC, the layout design of the ward will become reasonable. Meanwhile, relying on the development of the hospital, the proportion of medical staff will continue to be sufficient and the quality of personnel tends to high quality, so as to better promote the bundle strategies. In addition, the management of external personnel such as visitors and caregivers is still a difficult problem. Despite the experiencing of COVID-19 pandemic, the public hygiene habits have been greatly improved, but the awareness of MDRO is still insufficient. The active screening of neurosurgery CRE and the critical value information management intervention for the detection report of drug-resistant bacteria have not been fully promoted and implemented. These are the research goals that we will focus on next.

This study has several limitations that must be considered. Due to ethical considerations and practical conditions, we adopted a "before-after (pre-post) study", as a quasi-experimental design,[37,44] to evaluate the effectiveness of the intervention project. Although we referred to the books,[45] extended the baseline time to minimize the effect of bias, and assessed the impact of bias by making comparisons of patients' baseline characteristics, confounding factors were still difficult to avoid completely. We will optimize the study design, such as multicenter study, time series analysis, and multivariate regression method, to enhance the robustness of the next study. We also consider linking the study outcomes with patient prognosis and health economic evaluations for scientific research evidence to support CRO prevention and control efforts in similar medical institutions.

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Conclusion

In summary, the multidisciplinary and bundled intervention prevention and control practice, which is based on PDCA cycle management tool and is problem-oriented, has proven effective in controlling CROs in neurosurgery. The management of multi-drug resistant bacteria prevention and control requires the implementation of precise bundling measures tailored to national, hospital, and even departmental conditions. Continuous improvement should be achieved through real-time process supervision and data monitoring to more effectively enhance the prevention and control outcomes.

Data Sharing Statement

All data generated or analysed during this study are included in this published article.

Ethics Approval and Consent to Participate

Informed consent was waived because of the nature of the retrospective study and anonymous clinical data. This study was considered a quality improvement project and approved by the ethical committee of Shidong Hospital (2023-057-01). This study complies with the Declaration of Helsinki.

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Disclosure

The authors declare that they have no competing interests in this work.

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