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Innovative Solutions for Multidrug-Resistant Organisms' Infections in Intensive Care Unit: A Joint Efficacy Evaluation of Multidisciplinary Team and SHEL (Software, Hardware, Environment, Liveware) Model

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Background: The escalating threat of multidrug-resistant organisms (MDROs) in intensive care unit (ICU) demands innovative management strategies to curb the rising infection rates and associated clinical challenges.
Objective: To assess the effectiveness of integrating the multidisciplinary team (MDT) approach with the SHEL (Software, Hardware, Environment, Liveware) model in reducing MDRO infections within ICU settings.
Methods: From January 2021 to April 2024, a prospective, randomized controlled study was conducted in the ICU of Nantong Fourth People's Hospital, enrolling 411 patients with MDRO infections. These patients were randomly assigned into 3 groups: the MDT group, the SHEL model group, and a combined group. The intervention lasted for 4 weeks, during which the effects on the MDRO detection rate, infection rate, health care staff's infection control execution scores, and the rationality of antibiotic use were assessed, aiming to determine the efficacy of each approach in managing MDROs in the ICU setting.
Results: The overall infection rate of MDROs in the ICU of our hospital from 2021 to 2024 was 60.18%, with sputum infection sources accounting for 68.37% of the total sources, making it the primary source of infection. The detection rate of MDROs in the combined group was significantly higher than that in the MDT and the SHEL groups, with the SHEL group having a higher detection rate than the MDT group ($P < 0.05$). The infection rate of MDROs in the combined group was significantly lower than that in both the MDT and the SHEL groups, with the SHEL group having a lower detection rate than the MDT group ($P < 0.05$). The implementation scores of the combination group in standard prevention, hand hygiene, antibiotic management, and isolation measures were significantly higher than those of the MDT and SHEL groups, with the SHEL group scoring higher than the MDT group ($P < 0.05$). The rational use of antibiotics in the combined group was also higher than in both the MDT and the SHEL groups, with the SHEL group having a higher level than the MDT group ($P < 0.05$).
Conclusions: The integrated MDT and SHEL model significantly reduced MDRO infections in ICU, improved health care workers' infection prevention and nursing quality, and promoted the appropriate use of antibiotics, advocating for its clinical application.

Introduction

Multidrug-resistant organisms (MDROs) are bacteria that exhibit resistance to 3 or more classes of antimicrobial agents and are considered one of the main sources of hospital-acquired infections.[1] The alarming rise of MDROs in clinical settings, particularly within intensive care units (ICUs), has outpaced the development

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of new antimicrobial agents, presenting a formidable challenge to global public health.[2,3] Patients in the ICU have complex medical conditions and are often exposed to a multitude of antimicrobial agents, which significantly increases the risk of acquiring infections from MDROs. This situation leads to prolonged treatment times, increased treatment costs, and a higher mortality rate for individual patients. Moreover, it also poses a heightened risk of bacterial infections for the hospital as a whole.[4] MDROs in ICU include carbapenem-resistant enterobacteriaceae, vancomycin-resistant enterococcus (VRE), and methicillin-resistant *Staphylococcus aureus* (MRSA). These drug-resistant bacteria are not only resistant to a variety of antibiotics but also exhibit an increasing trend in resistance rates.[5] Therefore, the adoption of innovative and effective management strategies by hospitals is particularly important for the prevention and control of MDRO infections in the ICU.

Despite the recognition of MDROs as a significant threat, ICU management strategies have been found wanting in their ability to monitor and control the spread of these pathogens.[6] Contact transmission is the primary mode of spread for MDRO infections in the ICU. Traditional control models for multidrug-resistant bacteria involve health care workers implementing contact isolation based on the results of microbiological tests targeting carriers of MDROs.[7] However, these models may be insufficient to effectively prevent the spread, infection, and colonization of pathogenic microorganisms due to several issues, including the low level of knowledge, attitudes, and practices regarding MDRO infection control among health care workers, incomplete microbiological testing leading to missed detections, and the gap in contact isolation during the waiting period for microbiological results, which can lead to the continuous emergence of new sources of infection.[8–10] Hand hygiene is considered the most important measure for preventing health care–associated infections. It can be implemented by health care personnel to limit the cross-transmission of antimicrobial-resistant diseases by performing hand hygiene before and after patient contact, before aseptic procedures, after contact with patient body fluids, after patient contact, and after contact with the patient's surrounding environment.[11] Reports indicated that multimodal intervention measures could slightly reduce colonization and infection rates, with hand hygiene being an integral component.[12] However, studies have indicated that although hand hygiene has a certain effect on controlling and reducing the infection of MDROs, there are also issues with the infrastructure and processes in the ICU, such as the difference between single and multi-patient rooms. After changing from multi-patient to single rooms, the infection rates of VRE and MRSA have significantly decreased. The distance between patients and patient movement are also important factors that affect the infection rate of MDROs.[13] Furthermore, active surveillance and preventive measures are also applied in the defense against MDRO infections in the ICU, and although certain effects have been achieved, the complexity and variability of ICU epidemiology, such as invasive surgeries, improper use of broad-spectrum antibiotics, and immunosuppressants, pose challenges. Therefore, there is still a lack of more comprehensive and effective management and control measures currently.[4,6]

The multidisciplinary team (MDT) approach, which involves collaboration among various specialists, can be effective in enhancing infection control.[14] Collaboration between epidemiologists and microbiologists has been shown to facilitate the identification of transmission routes and mechanisms for MDRO infections. This collaboration is crucial for the development of effective, targeted prevention and control strategies.[15] Collaboration between clinical practitioners and pharmacologic experts can optimize the diagnosis and treatment of MDROs infections, ensuring that patients receive timely and effective care. Cooperation between health management experts and policymakers facilitates the development and implementation of hospital infection control policies, thereby enhancing the management of MDRO infections in health care facilities.[16] However, the integration of this approach with a systematic risk management framework has been limited, leaving a significant gap in our understanding of how to optimally manage MDRO infections in ICUs. The SHEL (Software, Hardware, Environment, Liveware) model, an Integrated Infection Control framework, offers a comprehensive human factors analysis by incorporating 4 essential components: software, hardware, environment, and liveware. This approach aims to facilitate the understanding and assessment of human factors issues providing recommendations for improvement.[17] It offers a comprehensive and accurate risk management framework that supports health care facilities in more effectively managing the risk of MDRO infections. Reports indicated that employing fishbone analysis alongside the SHEL model can pinpoint weaknesses in hospital infection control, leading to a significant reduction in the rate of MDRO infections and an enhancement in medical quality.[18]

This study integrated the MDT model with the SHEL model in ICU management, with the primary objective of assessing the effectiveness of this approach in reducing the incidence and severity of MDRO infections. Integration of the MDT with the SHEL model enables the development of more comprehensive, accurate, and effective risk management strategies. This integration assists health care facilities in better managing and mitigating the risk of MDRO infections in the ICU. The ultimate goal is to contribute to the improvement of the health care environment and the enhancement of patient safety through collaborative infection control and treatment management.

Materials and Methods

Study design

This study employed a prospective randomized controlled design, aiming to evaluate the efficacy of the combination of the MDT model and the SHEL model in managing MDRO infections in the ICU of our hospital. This study included 411 ICU patients diagnosed with MDRO infections, who were evenly allocated to 3 groups using the random number table method, with 137 patients in each group. To ensure the environmental hygiene of the ICU and to reduce the risk of transmission of MDROs, our hospital has implemented uniform cleaning and disinfection protocols for all ICU rooms and conducts regular microbiological monitoring. For nurses required to manage patients in different modalities, we have provided specialized training and used visual aids such as color coding to enhance accuracy. Additionally, this study has established a rigorous supervision and quality control system to ensure that all management measures are properly implemented and to enable a swift response to any issues that arise during the implementation process. This study has been approved by the hospital Ethics Committee (2021-K039). Experimental studies were carried out in accordance with the Declaration of Helsinki.

Participants

The study population consisted of 411 patients admitted to the ICU of Nantong Fourth People's Hospital from January 2021 to April 2024. A total of 411 ICU MDRO-infected patients were randomly divided into the MDT group ($n = 137$), the SHEL group ($n = 137$), and the combined group ($n = 137$). Eligible participants were identified based on specific criteria: Inclusion criteria were successful collection of sputum, urine, and other secretions before and after treatment, followed by bacterial culture and identification; the clinical data were complete; length of stay in the ICU > 5 days; there were no malignant tumors or significant organic lesions in

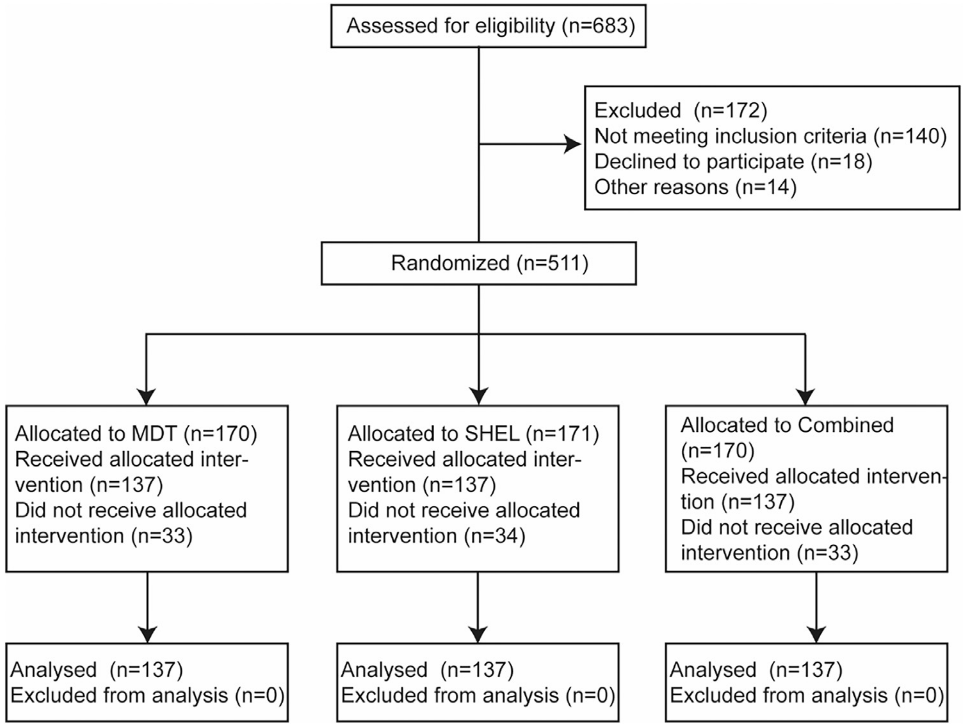

Figure. The recruitment diagram of the subjects. MDT = multidisciplinary team; SHEL = Software, Hardware, Environment, Liveware.

vital organs. All participants provided informed consent and participated in the study. Exclusion criteria were antibiotic treatment was administered within 30 days before the patient's admission, incomplete data, infections not originating within the hospital, and the presence of neurologic disorders, or communication barriers that could impede informed consent or data collection. Hospital-acquired infections refer to infections acquired by patients while in the hospital, including those that occur during hospitalization and those that manifest after discharge but were acquired in the hospital. This definition does not include infections that were already incubating or in progress at the time of admission. The recruitment diagram of the subjects was depicted according to the Consolidated Standards of Reporting Trials (CONSORT) statement, as shown in the Figure.

MDT combined with SHEL management strategy

Hospitals have introduced an advanced Infection Control Real-time Monitoring System (ICRS), in conjunction with an MDT of experts, to implement comprehensive surveillance and MDRO infections in the ICU. This process involves several key steps: (1) Formation of a MDT comprising a laboratory director, 6 ICU nurses, 2 principal representatives from the pharmacy department, and representatives from the medical department. The laboratory director was responsible for convening meetings to analyze existing management issues, providing feedback, offering suggestions for improvement, and collaboratively establishing a detailed management plan. Establishment of an MDRO Infection Expert Panel: Assembling professionals from intensive care, pharmacology, nursing, and infection control to provide expert consultation for clinical MDRO infections, including treatment plans, isolation measures, monitoring methods, and disinfection and cleaning protocols. (2) Proactive prevention: The ICRS system actively monitored patients' microbiological test results, and on detection of signs or history of MDRO infection, it triggered an early warning. These patients were immediately incorporated into the infection control program, with the implementation of standard precautions and contact isolation measures. Once the MDRO infection was confirmed, patients would be rapidly isolated to contain the spread. For patients without MDRO infection, isolation measures were lifted. The MDT conducted regular joint rounds to address clinical issues in real time. Additionally, every quarter, the laboratory and infection control department released reports on strain distribution and antibiotic resistance, assisting health care provided in promptly understanding infection dynamics and ensuring the timeliness and specificity of control measures. (3) Early intervention: Following an alert trigger in the hospital information system (HIS), the laboratory promptly notified the head of the MDT. The MDT then swiftly implemented infection control measures in response to the infection situation, effectively interrupting the transmission pathways of MDROs. (4) MDRO information: The HIS prominently displayed MDRO infection notifications to ensure that the receiving departments were alerted. This aided in the allocation of appropriate beds, scheduling of medical and technical services, and implementation of preventive measures. (5) Hardware configuration: The ICU intelligently assigned beds through the electronic medical record (EMR) system, ensuring the rational use of resources. Clinical environmental maintenance was achieved by cleaning and disinfecting high-touch surfaces such as bedrails, bedside tables, chairs, and medical equipment like monitors, ventilators, and stethoscopes 3 times daily. All cleaning activities were conducted using dedicated materials and are meticulously documented to ensure the quality and traceability of the disinfection process. Measurements of fluorescent material on surfaces were taken before and after cleaning, and the removal rate was calculated as (number of removed marks/number of marked points) × 100% = removal rate percentage. By comparing the removal rate of fluorescent marks before and after cleaning, we can assess the effectiveness of the cleaning and disinfection process. (6) MDRO management assessment: The hospital focused on the correct use of personal protective equipment, the standardized implementation of hand hygiene, and the compliance of disinfection and waste management practices.

During the interdisciplinary team's joint ward rounds, experts conducted a detailed assessment of these standards and promptly communicate the results to all hospital staff. The hospital also enhanced the understanding and awareness of MDRO infections among health care workers by organizing monthly training courses on MDRO control and prevention, as well as lectures on standard operating procedures, led by the infection control department. After the training session, a rigorous assessment was conducted to ensure that all participants have acquired the relevant knowledge. Furthermore, the hospital actively enhanced the overall awareness of infection prevention and control by organizing academic events, lectures, and distributing educational brochures. The regular Hand Hygiene Awareness Week encouraged the participation of patients and their families, highlighting the central role of hand hygiene in preventing hospital-acquired infections.

Procedures

The MDT group ($n = 137$) implemented standard in-hospital infection management. The management team adopted an MDT approach for managing MDROs. The MDT committee was composed of representatives from the laboratory, nursing, pharmacy, and medical affairs, and includes a vice-senior director as well as key department heads. The committee was tasked with creating a comprehensive, multidepartmental management plan for MDROs as well as establishing a regular meeting system to review and update the plan. The vice-senior director convened these meetings to analyze current issues, provide feedback, and propose improvements. They also conducted joint rounds in departments with high MDROs detection rates, addressing issues on-site. Quarterly, the laboratory and infection control department released clinical data on common strains and antibiotic resistance trends, including those of MDROs. They also assembled an expert team for the diagnosis and treatment of MDRO infections, which consists of core professionals and specialists from disciplines such as intensive care, clinical pharmacology, nursing, infection control, and microbiology. The team provided consultations on cases of MDROs infections, offering guidance on treatment, isolation protocols, monitoring practices, and procedures for disinfection and cleaning. The management team established evaluation standards and control strategies that incorporate a range of measures, including limiting equipment sharing, enhanced environmental cleaning, judicious antibiotic use, contact isolation, and an emphasis on hand hygiene. The hospital infection control department formulated MDRO management evaluation criteria, including personal protective equipment use, hand hygiene compliance, disinfection, and waste management. During joint rounds, subject matter experts assessed these criteria and communicate the findings to the entire hospital staff. The infection control department strengthened MDRO infection education and awareness by organizing training programs on topics such as MDRO control and prevention, as well as standard operating procedures. Department managers provide in-house training on MDRO infection knowledge, including training for facility managers and cleaners on disinfection and cleaning techniques. Post-training assessments ensured a 100% pass rate. The hospital actively promoted infection awareness through academic events, lectures, and the distribution of informational brochures.

The SHEL group ($n = 137$) employed the ICRS to closely monitor, analyze, and enhance clinical departments' infection control strategies concerning MDROs. These efforts were guided by the 4 fundamental elements of the SHEL model. (1) Proactive prevention: The ICRS tracked alerts on the patients' past microbiological test results. On diagnosis of a MDRO infection, patients were promptly separated to prevent the spread of infection. In contrast, a confirmed non-MDRO infection leads to the termination of isolation measures. This helped prevent MDRO transmission within the hospital. (2) Early intervention: MDRO detection was integrated into critical value management. On confirmation, HIS flashed alerts and marked the results, with the laboratory promptly notifying the clinical team. The doctor then issued isolation orders and records, promptly implementing infection control measures in daily practice. This helps to interrupt the MDRO transmission pathway. (3) MDRO information: HIS prominently displayed notifications for MDRO infection to ensure that receiving departments are alerted. This facilitated appropriate bed allocation, scheduling for medical and technical services, implementation of preventive measures, and thorough cleaning and disinfection processes. (4) Hardware components. (a) Bed allocation: The EMR displayed a real-time, card-based overview of bed arrangements in each ward, aiding managers in understanding single or bedside isolation and promoting rational bed allocation. (b) Clinical environment: Regular cleaning and disinfection, following guidelines like the Infection Control and Sterilization Technology Standard for Medical Institutions, were crucial. Surfaces like bedrails, nightstands, and chairs are wiped and disinfected 3 times daily, and medical equipment like monitors, ventilators, and stethoscopes was cleaned and disinfected 3 times daily. Dedicated cleaning materials were used, and each cleaning event is recorded. (c) Hand hygiene: Improving hand hygiene compliance was the most cost-effective and convenient strategy to prevent hospital-acquired infections and infections from MDROs. Various hand hygiene education activities were organized to reinforce hygiene awareness and adherence. The ICRS collects data on hand hygiene product usage across departments, and infection control specialists conduct monthly unannounced surveys on compliance, incorporating the results into monthly infection control evaluations. (d) Bedside equipment: Common medical items like thermometers, blood pressure monitors, and stethoscopes were provided at the patient's bedside. (e) Appropriate protective equipment, such as isolation gowns and face masks, was provided as needed.

The combined group ($n = 137$) involved dual MDT and SHEL management of ICU MDROs, with methods as described above.

Identification and testing of MDROs

The VITEK-2 compact microbiology analyzer was used for strain identification, and antimicrobial susceptibility testing was performed using ASTGN16 cards.[19] The results were interpreted according to the 2020 M100 guidelines from the Clinical and Laboratory Standards Institute, ensuring standardized and reliable detection of MDROs.[20]

Data collection

We recorded and analyzed the MDRO infection and distribution of MDRO strains in patients hospitalized in the ICU. After the intervention for 4 weeks, we recorded the detection rates of MDROs and hospital infection rates in each group, using the diagnostic criteria outlined in the Hospital Infection Diagnosis Standards.[21] Detection rate of MDROs:The detection rate of MDROs = (Number of MDROs positive samples/Total number of samples tested during the same period) $\times$ 100%. The infection rate of MDROs = (Number of new MDROs infection cases/Total population of the specific group during the same period) $\times$ 100%. A scoring scale for infection control execution scores for medical staff, which evaluated adherence to standard precautions, hand hygiene, antibiotic management, and isolation measures, has a total score of 100; a higher score indicates stronger implementation.[22] We compared the appropriateness of antibiotic usage using the Antibiotic Usage Reasonableness Rating Scale among 3 groups of antibiotic usage reasonableness.[23] Scoring ranges from 2 to 0, with 2 indicating complete compliance, 1 indicating partial compliance, and 0 indicating

Table 1
General information of patients in intensive care unit.

Category	Gender (male/female)	Age (y), mean (SD)	Length of ICU stay (d), mean (SD)
MDT group (n = 137)	116/21	83.64 (9.36)	28.10 (5.12)
SHEL group (n = 137)	108/29	81.71 (11.20)	27.50 (4.17)
Combined group (n = 137)	111/26	84.05 (8.32)	27.95 (9.36)
F/χ^2	1.582	2.274	0.305
P	0.453	0.104	0.737

ICU = intensive care unit; MDT = multidisciplinary team; SHEL = Software, Hardware, Environment, Liveware.

Table 2
Incidence of multidrug-resistant organism infections in intensive care unit patients.

Year	Number of ICU hospitalized cases	Number of infection cases	Rate of infection (%)	Number of infection episodes	Rate of infection episodes (%)
2021	133	83	62.41	128	25.60
2022	194	114	58.76	123	24.60
2023	257	159	61.87	126	25.20
2024	99	55	55.56	123	24.60
Total	683	411	60.18	500	100
χ^2			1.626		0.192
P			0.654		0.979

ICU = intensive care unit.

noncompliance. The higher the score, the more reasonable the antibiotic usage. Rationality rate = number of persons fully compliant/total number of people.

Statistical analysis

Data analysis was performed using SPSS 27.0 software (IBM SPSS, Chicago, IL, USA). All data were subjected to normality testing using the Shapiro-Wilk method, and all data followed a normal distribution. Count data is expressed in n (%), and comparison between groups is performed using χ^2 test. An independent sample t-test was used to analyze intergroup differences in quantitative data, and express them as mean ± SD. The significance level was predetermined at $P < 0.05$ to determine statistical significance.

Results

Participant demographics and equivalence among groups

The study included 411 ICU patients, with 137 patients in each of the MDT, SHEL, and combined groups. Table 1 summarizes the distribution of gender, age, and ICU stay, with no statistically significant differences shown in these characteristics across groups (gender: $F = 1.582$, $P = 0.453$; age: $F = 2.274$, $P = 0.104$; ICU stay: $F = 0.305$, $P = 0.737$), ensuring the comparability of the groups for the study's analysis.

Stability of MDRO infection rates in ICU patients over time

Given the significant impact of MDRO infections in the ICU setting on patient health and health care resources, timely understanding and assessing the time trends in these infection rates is critical to developing effective infection control strategies. We therefore analyzed the annual change in the rate of MDRO infection in ICU patients between January 2021 and April 2024 and assessed its stability over time. The results showed that a total of 683 patients were admitted to the general ICU, of which 411 patients were diagnosed with MDROs. The annual infection rates were 62.41% in 2021, 58.76% in 2022, 61.87% in 2023, and 55.56% in 2024, with a χ^2 test indicating no significant difference across the years ($\chi^2 = 1.626$, $P = 0.654$). Similarly, the infection episode rates were 25.60% in 2021, 24.60% in 2022, 25.20% in 2023, and 24.60% in 2024, with no significant variation noted ($\chi^2 = 0.192$, $P = 0.979$) (Table 2).

Distribution of MDRO strains

Subsequently, we evaluated the distribution and prevalence trend of MDRO strains among ICU inpatients from 2021 to 2024. As shown in Table 3, from January 2021 to April 2024, 500 MDRO-positive samples were collected from the general ICU, with 411 unique samples identified after eliminating duplicates. The distribution of these strains is as follows: MRSA with 15 strains (3.64%), carbapenem-resistant *Pseudomonas aeruginosa* (CRPA) with 113 strains (34.32%), carbapenem-resistant *Acinetobacter baumannii* (CRAB) with 30 strains (7.28%), carbapenem-resistant *Klebsiella pneumonia* (CRKP) with 88 strains (21.73%), and other MDROs with 224 strains (54.37%). The χ^2 test was applied to assess the statistical significance of the distribution changes over the years, with the results indicating no significant variation for MRSA ($\chi^2 = 1.023$, $P = 0.721$), CRPA ($\chi^2 = 1.231$, $P = 0.434$), CRAB ($\chi^2 = 2.254$, $P = 0.314$), CRKP ($\chi^2 = 0.965$, $P = 0.932$), and other MDROs ($\chi^2 = 1.302$, $P = 0.426$).

Comprehensive analysis of MDRO infection sources in ICU patients

The accurate identification of the source of MDRO infection in ICU patients is of great significance for the effective prevention and management of nosocomial infection and the formulation of targeted infection control strategies. This study further analyzed the distribution of specimen sources of MDRO infection in ICU patients, and evaluated the potential impact of different specimen sources on the infection rate to provide more accurate prevention guidance for clinical practice. As shown in Table 4, among 411 ICU patients, the sample sources of MDRO infection were as follows: urine samples accounted for 20.44%, sputum samples accounted for 68.37%, followed by blood samples accounted for 7.30%, and other sources of infection such as secretions, pus moss, and catheterized blood were relatively low. χ^2 test was used to evaluate the differences among different sources of infection, and the results showed that the χ^2 value was 1.302 and the *P* value was 0.426, indicating that there was no statistically significant difference.

Table 3
Distribution of multidrug-resistant organism strains in hospitalized patients in the general intensive care unit.

Strains	2021		2022		2023		2024			χ^2	P
	Number	Ratio (%)	Number	Ratio (%)	Number	Ratio (%)	Number	Ratio (%)	Overall ratio (%)		
MRSA	5	6.02	1	0.88	5	3.13	4	7.28	3.65	1.023	0.721
CRPA	24	28.92	20	17.54	51	31.88	18	32.73	27.49	1.231	0.434
CRAB	3	3.61	4	3.51	10	6.25	13	23.64	7.30	2.254	0.314
CRKP	10	12.05	12	10.53	6	3.75	2	3.64	7.30	0.965	0.932
Other	41	49.40	77	67.54	88	55.00	18	32.73	54.50	1.302	0.426
Total	83	100	114	100	159	100	55	100			

CRAB = carbapenem-resistant *Acinetobacter baumannii*; CRKP = carbapenem-resistant *Klebsiella pneumoniae;* CRPA = carbapenem-resistant *Pseudomonas aeruginosa*; MRSA = methicillin-resistant *Staphylococcus aureus*.

Table 4
Distribution of multidrug-resistant organism samples (number of strains) in hospitalized patients in the intensive care unit.

Specimen source	MRSA	CRPA	CRAB	CRKP	Other	Total	Component ratio (%)
Catheter	0	0	0	0	1	1	0.24
Catheter blood	0	0	0	0	2	2	0.49
Secretion	0	3	4	0	4	11	2.68
Urine	1	0	2	14	67	84	20.44
Pus moss	0	1	0	0	1	2	0.49
Sputum	13	105	24	14	125	281	68.37
Blood	1	4	0	1	24	30	7.30
Total	15	113	30	29	224	411	100

CRAB = carbapenem-resistant *Acinetobacter baumannii*; CRKP = carbapenem-resistant *Klebsiella pneumoniae*; CRPA = carbapenem-resistant *Pseudomonas aeruginosa*; MRSA = methicillin-resistant *Staphylococcus aureus*.

Table 5
Comparison of multidrug-resistant organism detection rates and infection rates among the 3 groups.

Category	Rate of MDRO detection (%)	Infection rate (%)
MDT group (n = 137)	6 (4.38)	21 (15.33)
SHEL group (n = 137)	13 (9.49)*	11 (8.03)*
Combined group (n = 137)	19 (13.87)*#	5 (3.65) *#
χ^2	7.365	11.643
P	0.025	0.003

MDRO = multidrug-resistant organism; MDT = multidisciplinary team; SHEL = Software, Hardware, Environment, Liveware.
Note: Compared with the MDT group
* $P < 0.05$; compared with the SHEL group
# $P < 0.05$.

Integrated management improved the detection rate of MDROs in ICU patients and decreased the infection rate

Detection and infection rates of MDROs in the ICU environment are key indicators for assessing patient tolerability and quality of care, and are essential for developing effective infection control strategies and optimizing treatment. Here, we further evaluated the impact of 3 different management strategies on the detection and infection rates of MDROs in ICU patients. According to the data in Table 5, the detection rate of MDROs in the combined group was significantly higher than that in the MDT and the SHEL groups, with the SHEL group having a higher detection rate than the MDT group ($P < 0.05$). The infection rate of MDROs in the combined group was significantly lower than that in both the MDT and the SHEL groups, with the SHEL group having a lower detection rate than the MDT group ($P < 0.05$).

Combined management strategy yields higher infection control compliance in ICU staff

In ICU, the infection control execution score of medical personnel is a key indicator to measure the quality of hospital infection management, which is crucial for reducing hospital infection rates and improving patient tolerability. Therefore, we evaluated the impact of 3 different management strategies, MDT, SHEL, and joint group, on the infection control execution scores of medical personnel (Table 6). The results showed that the implementation scores of the combination group in standard prevention, hand hygiene, antibiotic management, and isolation measures were significantly higher than those of the MDT and SHEL groups, with the SHEL group scoring higher than the MDT group ($P < 0.05$).

The joint management strategy significantly improved the rationality of antibiotic use among ICU medical staff

The rational use of antibiotics is crucial for controlling hospital-acquired infections, slowing down the development of drug resistance, and improving patient treatment outcomes, especially in high-risk environments such as ICU. We compared the rational use of antibiotics among 3 groups of ICU medical staff, and the results showed that compared with 85.40% (117/137) in the MDT group and 91.97% (126/137) in the SHEL group, the rational use rate of the combination group was significantly improved to 95.62% (131/137). The χ^2 test results showed that there was a statistically significant difference in the rationality of antibiotic use between the combination group and the other 2 groups ($\chi^2 = 10.507$, $P = 0.033$) (Table 7).

Discussion

In the face of the current severe challenges posed by MDRO infections in hospital ICUs, this study aims to provide a comprehensive prevention and control strategy for MDRO infections in ICU departments. By employing an MDT approach in conjunction with the SHEL management model, the research has demonstrated significant efficacy in reducing infections resistant to multiple drugs, bolstering the infection prevention capabilities among health care staff, and facilitating the judicious use of antibiotics.

This study employed MDT integrated with the SHEL model for the surveillance, analysis, and improvement of MDRO infections control in the ICU. The results revealed infection rates for each year from 2021 to 2024 were 62.41%, 58.76%, 61.87%, and 55.56%,

Table 6
Comparison of infection control execution scores for medical staff in 3 groups.

Category	Standard precautions	Hand hygiene	Antibiotic management	Isolation measures
MDT group (n = 137), mean (SD)	13.94 (9.63)	13.94(9.13)	11.32 (9.29)	14.13 (9.18)
SHEL group (n = 137), mean (SD)	16.01 (10.56)*	16.75 (9.63)*	16.15 (10.96)*	16.79 (10.54)*
Combined group (n = 137), mean (SD)	18.13 (12.33)*#	18.84 (12.15)*#	18.28 (12.36)*#	18.93 (12.09)*#
F	5.063	7.645	7.084	6.959
P	0.007	0.001	0.001	0.001

MDT = multidisciplinary team; SHEL = Software, Hardware, Environment, Liveware.
Note: Compared with the MDT group
* $P < 0.05$; compared with the SHEL group
# $P < 0.05$.

Table 7
Comparison of antibiotic usage reasonableness in 3 groups.

Category	Fully compliant (n)	Partially compliant (n)	Not in compliance (n)	Rationality rate (%)
MDT group (n = 137)	117	15	5	85.40
SHEL group (n = 137)	128	6	3	93.43*
Combined group (n = 137)	131	4	2	95.62*#
χ^2				10.507
P				0.033

MDT = multidisciplinary team; SHEL = Software, Hardware, Environment, Liveware.
Note: Compared with the MDT group
* $P < 0.05$; compared with the SHEL group
# $P < 0.05$.

respectively. There was no significant difference in the MDRO infection rates between the years ($P > 0.05$), but they were notably higher than the 50.51% reported by Li.[24] It may be due to the fact that our hospital has a strict infection control protocol, including hand hygiene, the use of personal protective equipment, and active screening and isolation measures for patients, all of which may help control the spread of MDROs. Additionally, our regular cleaning and disinfection of the ICU environment, implementation of antibiotic stewardship programs, and other measures may help control the survival and spread of MDROs in the hospital environment. The top 4 dominant strains detected in the general ICU of this hospital were CRPA, CRAB, CRKP, and MRSA. CRPA, CRAB, and CRKP are all carbapenem-resistant Gram-negative bacilli (CRGNB), which held a dominant position as the causative agents of MDRO infections within the ICU, consistent with the previous studies.[25]

Carbapenem antibiotics are potent and broad-spectrum, and are highly effective against Gram-negative bacteria, leading to a sharp rise in the detection rate of CRGNB. The accuracy and reliability of MDRO infections detection can vary significantly based on the sample source, highlighting the importance of standardized sampling protocols. For instance, samples obtained from blood, urine, sputum, and bronchoalveolar lavage fluid, as well as other sterile sites, may yield different results due to variations in the sampling method, storage conditions, and detection techniques used.[21,26,27] Sputum is a sample obtained directly from the lower respiratory tract and typically contains a higher concentration of pathogenic microorganisms. Compared with other samples, such as blood or urine, sputum more directly reflects the types and quantities of microorganisms causing pulmonary infections. Microorganisms in sputum samples have a high correlation with the patient's clinical symptoms and the site of infection. This makes sputum samples an important tool for assessing respiratory infections and guiding clinical treatment. The findings of our study indicated that sputum samples constituted 68.4% of the total, making them the most prevalent sample type. Urine samples followed at 20.4%. These results corroborate those of previous studies, which similarly identified sputum as a predominant source for MDRO detection.[28]

Research has shown that implementing measures such as hand hygiene, contact isolation, surveillance of antibiotic resistance, maintaining a clean environment, managing antibiotic usage, and providing education and training to health care personnel on resistance trends and control can significantly reduce the incidence of MDRO infections.[29] The findings of this study demonstrated a reduction in the incidence and detection rates of MDROs following the implementation of the MDT and SHEL combined management models in the ICU. This suggested that the combined MDT and SHEL management model enhanced the effectiveness of MDRO infections control in the ICU of this institution. This may be due to the interdisciplinary collaboration of the MDT, which ensured a comprehensive assessment and formulation of treatment plans for MDRO infections. This holistic perspective helped in the earlier identification and isolation of infected cases, thereby reducing the spread of MDROs. In addition, the application of the SHEL model provided health care workers with better tools and environments to control infections by improving hardware facilities, environmental conditions, and workflow processes, such as by enhancing hand hygiene facilities and isolation measures to reduce cross-infection. Hospital infection control standards are essential in preventing and controlling health care–associated infections, including preventive strategies, hand hygiene practices, antibiotic stewardship programs, and strict isolation protocols.[30] Health care personnel are the direct implementers of these measures, and their actions have a direct impact on the hospital infection rate. The effectiveness of infection control measures for health care workers is of paramount importance in the overall hospital infection control effort.[31] The study findings indicated that the health care worker infection control performance score was significantly higher in the combined MDT and SHEL intervention group compared with the MDT and SHEL control groups. This suggested that the integration of MDT with SHEL strategies can enhance the implementation and adherence to infection control measures for MDROs in the ICU setting.

Additionally, the results of this study also indicated that the rate of appropriate antibiotic usage in the MDT combined with SHEL group was 95.62%, significantly higher than the 85.40% in the MDT group and 93.43% in the SHEL group. This may be attributed to the proactive preventive measures within the MDT combined with the SHEL model of this study, where the MDT promptly disseminated reports on the distribution of strains and their antimicrobial resistance profiles. Additionally, training on antibiotic use and the dissemination of infection prevention knowledge to health care staff, patients, and their families effectively enhanced the rational use of antibiotics. Consistent with earlier studies, the results also confirmed that the MDT and SHEL models could enhance the rational use of antibiotics in hospitals.[19,32]

Despite the positive results of this study, there are some limitations. For example, sample origin may affect the accuracy of detection of MDRO infection, and the proportion of different sample types may affect the universality of results. Future studies need to expand the sample size, extend the follow-up time, and consider applicability in different regions and medical settings. Our research findings are primarily applicable to middle-aged and elderly patients, and their applicability to younger individuals may be limited. Future research could expand the age range, especially to include younger populations. In addition, the integration of real-time data and advances in technology, such as AI-assisted diagnosis, may provide more precise and effective means of infection control.

Conclusions

The integration of MDT with the SHEL management model addressed the issues associated with MDT, such as the lack of coordination among specialized personnel and a systematic risk management framework, while simultaneously tackling the limitations of the SHEL model, including constraints on hardware and software resources, uncontrollability of environmental factors, and the lack of professionalism in infection control and prevention. It enhanced the complementary strengths between the 2 approaches. In conclusion, the infection of an MDT approach with the SHEL model has significantly curtailed the prevalence of MDRO infections in the ICU. This synergistic model has enhanced the infection prevention practices among health care workers, elevated the standard of nursing care, and fostered the judicious use of antibiotics, thereby underscoring its potential for widespread clinical implementation. Therefore, it is worth promoting and implementing in health care settings.

Declaration of competing interest

The authors declare no conflict of interest.

Author Contributions

X. Kang, Z. Feng, and B. Yin have contributed to conceptualization of this study. P. Zhang and Q. Xu were involved in the study methodology and formal analysis. X. Kang, P. Zhang, and Q. Xu were involved in investigation of the study; X. Kang and P. Zhang involved in writing—original draft preparation. X. Kang, Q. Xu, Z. Feng, and B. Yin involved in writing—review and editing. B. Yin was responsible for supervision and funding acquisition. All authors have read and agreed to the published version of the manuscript.

Data Availability Statement

Data are available from the corresponding author upon reasonable request.

Patient Consent and Ethics Committee Approval

The study was conducted according to the guidelines of the Declaration of Helsinki, and approved by the ethics committee of Nantong Fourth People's Hospital (reference number: N0 2021-K039). Informed consent was obtained from all subjects involved in the study.

References

1. Kernéis S, Lucet JC. Controlling the diffusion of multidrug-resistant organisms in intensive care units. *Semin Respir Crit Care Med*. 2019;40:558–568.
2. Garcia-Parejo Y, Gonzalez-Rubio J, Garcia Guerrero J, et al. Risk factors for colonisation by multidrug-resistant bacteria in critical care units. *Intensive Crit Care Nurs*. 2024;86:103760.
3. Yassin A, Uralska M, Pogue JM, et al. State of the management of infections caused by multidrug-resistant gram-negative organisms. *Clin Infect Dis*. 2023;77:e46–e56.
4. Han Y, Zhang J, Zhang HZ, et al. Multidrug-resistant organisms in intensive care units and logistic analysis of risk factors. *World J Clin Cases*. 2022;10:1795–1805.
5. Fan ZY, You SJ, Li LB, et al. Multidrug-resistant organism infections of inpatients in a hospital in Eastern China from 2015 to 2021. *Infect Drug Resist*. 2023;16:4387–4395.
6. Ruiz-Ramos J, Ramírez P. Antimicrobial stewardship programs in the intensive care unit in patients with infections caused by multidrug-resistant Gram-negative bacilli. *Med Intensiva (Engl Ed)*. 2023;47:99–107.
7. Iordanou S, Palazis L, Timiliotou-Matsentidou C, et al. When multidrug-resistant organism (MDRO)-positive ICU patient isolation and cohorting is not feasible, what comes next? *Cureus*. 2021;13:e13636.
8. Saliba R, Karam-Sarkis D, Zahar JR, Glélé LSA. Adverse events associated with patient isolation: a systematic literature review and meta-analysis. *J Hosp Infect*. 2022;119:54–63.
9. Di Lodovico S, Fasciana T, Di Giulio M, et al. Spread of multidrug-resistant microorganisms. *Antibiotics (Basel)*. 2022;11:832.
10. Alshamrani MM, El-Saed A, Al Zunitan M, et al. Novel preventive bundle for multidrug-resistant organisms in intensive care setting; tertiary care experience. *Heliyon*. 2024;10:e28072.
11. Lotfinejad N, Peters A, Tartari E, et al. Hand hygiene in health care: 20 years of ongoing advances and perspectives. *Lancet Infect Dis*. 2021;21:e209–e221.
12. Derde LPG, Cooper BS, Goossens H, et al. Interventions to reduce colonisation and transmission of antimicrobial-resistant bacteria in intensive care units: an interrupted time series study and cluster randomised trial. *Lancet Infect Dis*. 2014;14:31–39.
13. Bertuzzi A, Martin A, Clarke N, et al. Clinical, humanistic and economic outcomes, including experiencing of patient safety events, associated with admitting patients to single rooms compared with shared accommodation for acute hospital admissions: a systematic review and narrative synthesis. *BMJ Open*. 2023;13:e068932.
14. Sandiford NA, Wronka K. The multidisciplinary approach to managing prosthetic joint infection: could this lead to improved outcomes? *Ann Jt*. 2022;7:8.
15. Sy CL, Chen PY, Cheng CW, et al. Recommendations and guidelines for the treatment of infections due to multidrug resistant organisms. *J Microbiol Immunol Infect*. 2022;55:359–386.
16. Nohl A, Hamsen U, Jensen KO, et al. Incidence, impact and risk factors for multidrug-resistant organisms (MDRO) in patients with major trauma: a European Multicenter Cohort Study. *Eur J Trauma Emerg Surg*. 2022;48:659–665.
17. Doi T. The relationship between the living environment and remote working: an analysis using the SHEL model. *PeerJ*. 2024;12:e17301.
18. Gai YY, Ding HL, Ma JL. Application of fishbone analysis and SHEL model for risk management of hospital infections with multi-drug resistant organisms. *J Qilu Nurs*. 2024;30:159–161.
19. Zhao CT, Yu J, Shen XL, et al. Study on the application effect of multidisciplinary collaboration in the prevention and control of infections with multi-drug resistant organisms. *China Health Stand Manag*. 2022;13:155–158.
20. Liang M, Liu Q. Distribution and risk factors of multidrug-resistant bacteria infection in orthopedic patients. *J Healthc Eng*. 2022;2022:2114661.
21. Li Z, Zhu D, Ma X, et al. Implications of deduplication on the detection rates of multidrug-resistant organism (MDRO) in various specimens: insights from

the hospital infection surveillance program. *Antimicrob Resist Infect Control*. 2024;13:54.
22. Lin XF, Lai LY. Application of MDT and critical value management in hospital infections caused by multidrug-resistant organisms in hospitals. *China Health Stand Manag*. 2023;14:169–173.
23. Smith RM, Lautenbach E, Omulo S, et al. Human colonization with multidrug-resistant organisms: getting to the bottom of antibiotic resistance. *Open Forum Infect Dis*. 2021;8:ofab531.
24. Li ZJ, Wang KW, Liu B, et al. The distribution and source of MRDOs infection: a retrospective study in 8 ICUs, 2013-2019. *Infect Drug Resist*. 2021;14:4983–4991.
25. Raj N, Agarwal J, Singh V, et al. A retrospective analysis of the 5-year trends of antimicrobial resistance in gram-negative bacterial isolates from an intensive care unit at a tertiary care hospital. *Int J Crit Illn Inj Sci*. 2023;13:178–183.
26. Ling L, Wong WT, Lipman J, Joynt GM. A narrative review on the approach to antimicrobial use in ventilated patients with multidrug resistant organisms in respiratory samples-to treat or not to treat? That is the question. *Antibiotics (Basel)*. 2022;11:452.
27. Li Z, Zhang Y, Zhang W, et al. Study on the detection and infection distribution of multidrug-resistant organisms in different specimens. *Infect Drug Resist*. 2022;15:5945–5952.
28. Diab-Elschahawi M, Lusignani LS, Starzengruber P, et al. The strength of coughing may forecast the likelihood of spread of multi-drug resistant microorganisms from the respiratory tract of colonized patients. *Antimicrob Resist Infect Control*. 2014;3:38.
29. Thomas RE, Thomas BC, Lorenzetti D, Conly J. Hospital and long-term care facility environmental service workers' training, skills, activities and effectiveness in cleaning and disinfection: a systematic review. *J Hosp Infect*. 2022;124:56–66.
30. Bredin D, O'Doherty D, Hannigan A, Kingston L. Hand hygiene compliance by direct observation in physicians and nurses: a systematic review and meta-analysis. *J Hosp Infect*. 2022;130:20–33.
31. Kubde D, Badge AK, Ugemuge S, Shahu S. Importance of hospital infection control. *Cureus*. 2023;15:e50931.
32. Brayson J, Barrett S, Baqir W, et al. CATALYST: challenging antibiotic allergy status. *J Antimicrob Chemother*. 2023;78:1241–1244.