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Bundled Management for Control of Environmental Contamination by Multidrug-Resistant Organisms in ICU

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ABSTRACT: Objective This study aims to evaluate the effectiveness of bundled management measures in controlling environmental contamination by multidrug-resistant organisms (MDROs) in the intensive care unit (ICU), and to provide a practical basis for reducing the risk of MDRO contamination in the ICU environment and decreasing the incidence of nosocomial infections. **Methods** Patients colonized or infected with MDROs in the ICU were screened using the hospital-acquired infection surveillance system. Environmental hygiene monitoring was performed on high-frequency contact surfaces of MDRO patients, healthcare workers' hands, medical textiles, and sinks. The fluorescent labeling method was employed to monitor the implementation of surface cleaning and disinfection in the ICU. Targeted bundled rectification measures were then implemented, and environmental hygiene monitoring and evaluation were repeated after four months. **Results** A total of 90 samples were collected from high-frequency contact surfaces, textiles, and sinks in the ICU both before and after the intervention. Following the implementation of targeted rectification measures, the detection rate of microbial specimens decreased from 71.11% to 17.78% with a statistically significant difference (P<0.05). For environmental cleaning monitored using the fluorescent labeling method, 960 points were marked before the intervention, of which 367 were cleared; after the intervention, 950 points were marked, and 830 were cleared. The clearance rate increased from 38.23% before the intervention to 87.36% after the intervention, and the difference was statistically significant (P<0.05). **Conclusion** Implementation of corresponding environmental rectification measures can reduce environmental surface contamination by MDROs in the ICU, effectively interrupt transmission routes, and decrease the incidence of nosocomial infections.

KEY WORDS: Multidrug-resistant organism (MDRO); Surface cleaning and disinfection; Monitoring; Bundled management measures

1 Introduction

Nosocomial infections caused by multidrug-resistant organisms (MDROs) is a significant concern. MDROs are defined as bacteria that are resistant to at least three classes of clinically used antimicrobial agents[1]. Data from the China Antimicrobial Resistance Surveillance System indicate that MDRO detection rates vary among medical institutions of different levels and regions[2]. In 2024, the National Health Commission of the People's Republic of China updated the quality control indicators for hospital infection management, in which monitoring of MDRO nosocomial infections remains a key component[3]. Consequently, controlling and reducing the cross-transmission of MDROs within healthcare facilities has become a top priority for hospital management.

Multiple studies have demonstrated that three key measures, including contact precautions, patient isolation, and environmental cleaning, are critical for effectively controlling the in-hospital spread of MDRO infections[6]. During routine inspections and upon receiving early warnings from the hospital infection surveillance system, the Department of Infection Management promptly conducted epidemiological investigations and environmental hygiene monitoring for patients infected with MDROs in the ICU, focusing on high-frequency contact surfaces. This research was conducted to assess the quality of environ-

mental cleaning and disinfection, with the goal of rapidly identifying weak links and preventing infections through integrated management strategies.

2 Subjects and Methods

2.1 Study subjects

This study randomly selected four months (January, March, October, and December) in 2024 to evaluate the cleaning and disinfection quality of various items in the ICU, including bed units and high-frequency contact surfaces, instruments and equipment (e.g., bed rails, bedside tables), treatment-related items (e. g., ventilators, monitors, infusion pumps), computer keyboards and mice, healthcare workers' uniforms and hands, sinks, and textiles. Visual inspection, fluorescent labeling, and microbiological methods were employed.

2.2 Environmental hygiene monitoring

Environmental surface cleaning and disinfection monitoring were performed using visual inspection, fluorescent labeling, and microbiological methods. Fluorescent labeling was conducted monthly, and microbiological monitoring was conducted quarterly.

2.2.1 Fluorescent labeling

Fluorescent markers were pre-applied to high-frequency contact environmental surfaces before the environmental cleaning staff performed cleaning. A blinded method (in which only the marker knew the marked spots) was used to designate points on bed units and instrument surfaces. Before cleaning and disinfection, a uniform mark, a five-pointed star with a diameter of 2 cm, was drawn at fixed positions using a fluorescent marker pen to ensure consistency and standardization of the marking. The locations and quantity of marked points were accurately recorded. After cleaning and disinfection, an ultraviolet lamp was used to verify whether the fluorescent markers had been effectively removed. The effective clearance rate of fluorescent markers was calculated and recorded. If no fluorescent marker was observed, the cleaning quality was considered qualified; otherwise, it was considered unqualified.

$$\text{Fluorescent marker clearance rate} = \frac{\text{Qty. of fluorescent markers cleared}}{\text{Total qty. of fluorescent markers}} \times 100\%$$

2.2.2 Sampling

A sterile swab moistened with sterile eluent was used to sample a surface area of 100 cm^2. For irregularly shaped small objects, such as a computer mouse, the entire surface was swabbed. After sampling, the swab was placed into a test tube containing 10 mL of neutralizer, and the tube was vigorously shaken. Then, 1.0 mL of the eluent at different dilution factors was withdrawn and inoculated onto plates. Molten nutrient agar medium cooled to 40℃ to 45℃ was poured into each plate (15~20 mL per plate). The plates were incubated at 36℃±1℃ for 48 hours, and the number of colonies was counted. A sample was considered qualified if the microbial count was ≤5 colony-forming units (cfu)/cm^2.

Surface sampling and colony culture methods were performed in accordance with the *Regulation of disinfection technique in healthcare settings* (2012 edition). Samples with abnormal monitoring results were subjected to strain identification. Specimens were cultured and identified by professional technicians in the microbiology laboratory following the *National Clinical Laboratory Operating Procedures*.

2.3 Statistical analysis

Statistical analyses were performed using SPSS version 27.0. Categorical variables were presented as counts and percentages (%). Between-group comparisons were conducted using the chi-square (X^2) test. A P value of <0.05 was considered statistically significant.

2.4 Bundled management measures

2.4.1 Improvement of management

The heads of the Department of Infection Management, the Medical Affairs Office, the Nursing Department, the General Affairs Department, and the Property Management Department, together with relevant staff from the clinical department, convened an on-site multi-department coordination meeting to identify and analyze existing problems.

(1) Early identification of patients and implementation of isolation measures. Physicians are required to promptly monitor MDRO alerts and laboratory reports in the Hospital Infection Information System. When a patient is identified as having an MDRO, healthcare workers should, before bed placement, first assess whether high-risk patients (e. g., those with endotracheal intubation, central venous catheterization, or immunocompromised status) occupy the same room and avoid placing the MDRO patient in that room whenever possible. Second, nursing staff should be instructed to affix a blue contact isolation label to the bedside, the medical record, and the inpatient list to alert all healthcare workers in the ward. The patient's wristband should be marked with "MDRO" using a red marker. When transferring the patient, the receiving department must be informed that the patient is colonized or infected with an MDRO.

(2) One infection control nurse was designated per department to be responsible for surface cleaning and disinfection. In collaboration with the property management supervisor, this nurse supervised the cleaning and disinfection performance of the cleaning staff, ensuring that routine environmental cleaning and disinfection were performed twice daily. The frequency of cleaning and disinfection for high-touch instrument surfaces was changed to after each nursing shift, with immediate cleaning and disinfection upon visible contamination.

(3) Joint supervision. Self-inspections were carried out by department infection control specialists and cleaning supervisors, while spot checks were conducted by the Nursing Department and full-time infection control staff to verify the implementation of cleaning and disinfection practices.

2.4.2 Revision of policies and procedures related to MDRO management

The *Flow Chart for MDRO Infection Control* and the *Hospital Infection Control Procedures for Intensive Care Unit and General Ward Units* were established to enhance the cleaning and disinfection of the care environment for patients with MDRO infection or colonization.

2.4.3 Training

Stratified training on disinfection, isolation knowledge, and operational skills was provided for healthcare workers, nursing assistants, and cleaning staff. The importance of routine cleaning and disinfection was emphasized based on the sampling results. Theoretical instruction and on-site demonstrations were used to clarify correct cleaning and disinfection procedures. On-site assessments were conducted after training, and non-standard operations as well as errors were promptly corrected. Each trainee was assessed individually.

Hand hygiene awareness among ward staff was reinforced through regular lectures and operational demonstrations. Hand hygiene compliance among healthcare workers, nursing assistants, and cleaning staff was observed and recorded monthly to improve adherence.

2.4.4 Personal protective equipment

The frequency of changing work uniforms for healthcare workers, nursing assistants, and cleaning staff increased from twice per week to three times per week. Disposable isolation gowns were required when providing patient care.

3 Results

3.1 Bacterial culture results from high-frequency contact surfaces before and after intervention

A total of 90 samples were collected from various surface types before and after the intervention. Multiple surface samples showed bacterial counts exceeding the acceptable standard. Microbiological culture results indicated that the detection rate of bacteria on high-frequency contact environments and surfaces before intervention was 71.11%, which decreased to 17.78% after intervention; the difference was statistically significant (P<0.001). The detection rates on instrument surfaces, bed rails, computer keyboards, cleaning tools, medical waste container surfaces, textiles, and work uniforms decreased significantly after intervention (all P<0.05). The comparison of bacterial culture results before and after intervention is shown in Table 1.

Among the samples that exceeded the accept-

Table 1 Comparison of bacterial culture from high-frequency contact environments and items before and after intervention

Sampling site	Before intervention		After intervention		X^2	P
	Detection rate (%)	Identified microorganism (s)	Detection rate (%)	Identified microorganism (s)		
Instrument surfaces	66. 67 (8/12)	*Bacillus cereus*	16. 67 (2/12)	—	6. 17	0. 013
Bed rails	83. 33 (10/12)	*Pseudomonas montellii*	0. 00 (0/12)	—	17. 14	<0. 001
Sinks	75. 00 (6/8)	—	50. 00 (4/8)	*Pseudomonas aeruginosa*	1. 07	0. 302
Floor drains	75. 00 (6/8)	*Pseudomonas aeruginosa*	50. 00 (4/8)	—	1. 07	0. 302
Computer keyboards	83. 33 (10/12)	Mold	16. 67 (2/12)	—	10. 67	0. 001
Cleaning tools & medical waste container surfaces	100. 00 (8/8)	*Bacillus cereus*	37. 50 (3/8)	—	7. 27	0. 007
Textiles	75. 00 (6/8)	—	0. 00 (0/8)	—	9. 60	0. 002
Work uniforms	66. 67 (8/12)	*Staphylococcus aureus*	8. 33 (1/12)	—	8. 71	0. 003
Healthcare workers' hands	20. 00 (2/10)	—	0. 00 (0/10)	—	2. 22	0. 136
Total	71. 11 (64/90)		17. 78 (16/90)		51. 84	<0. 001

able standard, mass spectrometry was used for further identification. Different bacteria were detected in multiple samples. The distribution of detected microorganisms showed that most were gram-negative bacilli and gram-positive cocci. *Bacillus cereus* was detected in multiple environments (Table 1).

3.2 Fluorescent labeling results on high-frequency contact surfaces before and after intervention

Fluorescent labeling monitoring of high-frequency contact surfaces before and after the intervention showed that the clearance rates for the left bed rail's inner button, the bed end rail, and the mouse/keyboard increased from 34.29%, 32.00%, and 36.00% before the intervention to 91.43%, 74.29%, and 86.00% after the intervention, respectively, with all differences being statistically significant (all P<0.05; Table 2).

4 Discussion

Patients admitted to the ICU frequently present

Table 2 Comparison of fluorescent labeling results on high-frequency contact surfaces before and after intervention

Sampling site	Before intervention			After intervention			X^2	P
	Qty. of marked points	Qty. cleared	Clearance rate (%)	Qty. of marked points	Qty. cleared	Clearance rate (%)		
Left bed rail	70	40	57. 14	70	65	92. 85	23. 81	<0. 001
Left bed rail - outer button	70	28	40. 00	70	64	91. 43	41. 09	<0. 001
Left bed rail - inner button	70	24	34. 29	70	64	91. 43	48. 95	<0. 001
Right bed rail	70	22	31. 43	70	58	82. 86	37. 80	<0. 001
Right bed rail - outer button	70	21	30. 00	70	54	77. 14	31. 27	<0. 001
Right bed rail - inner button	70	18	25. 71	70	64	91. 43	62. 29	<0. 001
Bed end rail	60	16	32. 00	70	52	74. 29	29. 37	<0. 001
Bedside table	50	26	52. 00	50	48	96. 00	25. 16	<0. 001
Bedside desktop	70	32	45. 71	70	60	85. 71	24. 86	<0. 001
Treatment cart	50	36	72. 00	50	46	92. 00	6. 78	<0. 009
Yellow waste bin	70	18	25. 71	60	52	86. 67	48. 30	<0. 001
Black waste bin	70	16	22. 86	60	53	88. 33	55. 61	<0. 001
Pendant/ceiling unit	50	22	44. 00	50	46	92. 00	26. 47	<0. 001
Instrument surfaces	70	30	42. 85	70	61	87. 14	30. 17	<0. 001
Mouse/keyboard	50	18	36. 00	50	43	86. 00	26. 27	<0. 001
Total	**960**	**367**	**38. 23**	**950**	**830**	**87. 36**	**492. 83**	**<0. 001**

with complex conditions, many of which involve severe infections, extensive antibiotic use, and a high prevalence of multidrug resistance, accompanied by a diverse range of pathogenic bacteria. Zhang et al.[4] reported that the predominant pathogens isolated from the ICU were *Acinetobacter baumannii* and *Klebsiella pneumoniae*, exhibiting severe drug resistance. MDROs, which are transmitted via contact, can readily contaminate surfaces because of staff negligence. The ICU environment, including the air, medical equipment, bed unit surfaces, and healthcare workers' hands, may serve as reservoirs or colonization sites for various pathogens and multidrug-resistant opportunistic pathogens, potentially leading to nosocomial infection outbreaks[5]. Therefore, early identification of MDROs and the implementation of effective infection prevention and control measures are essential to reduce the occurrence of hospital infection outbreaks.

Non-standard operations by cleaning staff can directly or indirectly lead to the transmission of pathogenic microorganisms, making this group a key focus of hospital infection control. Due to generally low educational levels, older age, insufficient knowledge comprehension, and weak awareness of infection prevention among cleaning staff, training remains challenging. Shi et al.[7] showed that after targeted multi-format training for cleaning staff, the pass rate of hospital infection knowledge improved significantly. Fluorescent labeling, as an environmental hygiene monitoring tool, can intuitively and rapidly evaluate disinfection effects and has been well validated in multiple studies[8-9]. Qin et al.[10] demonstrated that fluorescent labeling can effectively address cleaning blind spots and improve cleaning outcomes significantly. In this study, fluorescent labeling was used to monitor the cleaning and disinfection effectiveness of environmental surfaces, providing a convenient, intuitive, and effective means to improve the quality of cleaning and disinfection around patients. The detection of *Bacillus cereus* in multiple environments indicates that insufficient wiping force during routine cleaning fails to thoroughly remove bacteria from surfaces, thereby compromising disinfection effectiveness. Therefore, in subsequent training and practice drills, emphasis should be placed on adequate wiping force because insufficient force cannot remove surface-colonizing bacteria. Upon patient discharge, thorough, no-blind-spot cleaning and disinfection of the bed unit, environmental surfaces, and air should be performed. Given the varying educational levels of cleaning staff, fluorescent labeling can help guide work, directly indicating areas often missed during routine cleaning and assisting them in correcting improper cleaning and disinfection methods.

The role of hand hygiene in the prevention and control of hospital infections is widely acknowledged. However, the causal relationship between environmental contamination in healthcare settings and healthcare-associated infections remains somewhat debated. Nonetheless, accumulating evidence suggests that outbreaks of healthcare-associated infections are closely associated with the prolonged survival of pathogenic microorganisms in the environment. Therefore, improving environmental hygiene may reduce the incidence and outbreak of hospital infections[11].

Strengthening comprehensive testing and disinfection of the ICU environment and patient-related medical supplies can reduce the spread and cross-infection of Carbapenem-resistant *Acinetobacter baumannii* (CRABA) strains[12]. This study demonstrates that implementing bundled management measures, including developing protocols and procedures, providing stratified training, strengthening supervision, and enhancing environmental cleaning and disinfection, can effectively ameliorate severe environmental surface contamination in the ICU, reduce the incidence of nosocomial infections, and provide practical experience for the prevention and control of MDRO nosocomial infections.

Nevertheless, this study has several limitations. First, the sample size is relatively small, and this was a single-center study, which may limit the generalizability of the findings. Future multicenter, large-sample studies are needed to further validate the applicability and effectiveness of bun-

dled management measures in various ICU settings. Second, this study primarily focused on the effectiveness of cleaning and disinfection of environmental surfaces and bacterial culture pass rates, without conducting an in-depth analysis of the direct impacts on patient clinical outcomes, such as MDRO infection rates or length of hospital stay. Subsequent studies should further investigate the specific effects of bundled management measures on patient prognosis to provide stronger evidence for their clinical implementation. Additionally, the long-term sustainability of these bundled measures warrants attention. Establishing a long-term mechanism to ensure continuous and effective implementation of all measures, and to avoid rebound effects due to staff turnover or waning awareness, are important issues to be addressed in future work. Despite these limitations, the results of this study suggest that bundled management for MDRO environmental contamination in the ICU is an effective strategy. Its core lies in systematically and normatively enhancing infection control awareness among all personnel, optimizing cleaning and disinfection procedures, and supplementing these with effective monitoring and feedback mechanisms, thereby interrupting MDRO transmission routes and ensuring patient safety. These findings also provide a useful reference for infection prevention and control in other healthcare facilities, especially in key departments such as intensive care units. In the future, information technologies, such as Internet of Things (IoT) devices for real-time monitoring of environmental cleaning quality and intelligent reminders for cleaning and disinfection operations, could be integrated to further improve the precision and intelligence of ICU environmental contamination control.

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