Preplanned Studies

Retrospective Analysis of the Molecular Links Among Clustered Cases of *Acinetobacter baumannii* Nosocomial Infections Occurring in Different Years within the ICU — Jiangsu Province, China, 2016–2021

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Summary

What is already known about this topic?

Carbapenem-resistant *Acinetobacter baumannii* (CRAB) is a well-established cause of difficult-to-treat nosocomial infections, particularly in intensive care units (ICUs). This strain is known for its ability to persist in hospital environments, leading to outbreaks.

What is added by this report?

This retrospective study analyzed five separate CRAB nosocomial infection clusters that occurred in 2016, 2019, and 2021. This revealed the molecular epidemiological links between cases and environmental samples across different years, suggesting the potential for ongoing environmental transmission. Following intensive terminal disinfection, no homologous pathogens have been detected since 2021.

What are the implications for public health practice?

The potential risk of environmental transmission suggests that the current bedside isolation strategies may have deficiencies. Given that the prevailing ICU multibedroom configuration remains unchanged, additional effective disinfection methods must be developed urgently. These techniques should specifically target high-touch irregular surfaces to disrupt persistent CRAB transmission.

ABSTRACT

Introduction: To investigate the molecular epidemiological links among clustered cases of carbapenem-resistant *Acinetobacter baumannii* (CRAB) nosocomial infections occurring in different years within an intensive care unit (ICU) in Jiangsu Province, China and identify gaps in infection control in multibed ICU settings.

Methods: A retrospective study was conducted on five clusters of CRAB infections in 2016, 2019, and 2021. Twenty clinical and forty environmental *A. baumannii* isolates were analyzed using pulsed-field gel electrophoresis (PFGE) for molecular typing, and antimicrobial susceptibility testing for resistance profiling.

Results: PFGE revealed high genetic similarity (>90%) among clinical and environmental isolates from 2016, 2019, and 2021, indicating the persistent environmental transmission of CRAB over multiple years. All patient-derived strains were CRAB strains. No homologous strains were detected after thorough disinfection of the terminals in 2021.

Conclusions: CRAB demonstrated remarkable environmental persistence in ICUs, suggesting limitations in current disinfection practices. Enhanced disinfection strategies targeting high-touch complex surfaces are necessary to interrupt CRAB transmission and reduce nosocomial outbreaks.

Acinetobacter baumannii is a conditionally pathogenic gram-negative bacterium that has emerged as a major pathogen causing hospital infection outbreaks because of its ability to adapt to various environmental conditions. As a critical multidrug-resistant pathogen in nosocomial infections, *A. baumannii* has accounted for more than 10% of all gram-negative hospital infections in intensive care units (ICUs) in Europe and the United States over the last 10 years, and this proportion continues to rise (*1*–*2*). The mortality rate associated with nosocomial outbreaks, which were mainly reported from ICUs (104 in ICU/150 total), caused by *A. baumannii* is approximately 48% multi-drugresistant and 42.5%

non-multidrug resistant (3). Moreover, the World Health Organization (WHO) has classified Carbapenem-resistant *Acinetobacter baumannii* (CRAB) as a critical group of bacteria that poses the most severe threat to human health (4).

In China, this situation is of equal concern and cannot be overlooked. The 2023 China Bacterial Drug Resistance Surveillance revealed that *A. baumannii* accounted for 87.6% of Acinetobacter spp. The resistance rates of these strains to all antibiotics except polymyxin and tigecycline exceeded 48%. The resistance rates of *A. baumannii* to meropenem and imipenem were 73.7% and 73.4%, respectively, ranking fourth among the top 20 most important clinical isolates (5). Owing to its pan-drug resistance, *A. baumannii* has become a formidable challenge for infection control in intensive care wards and a notable cause of death among patients with severe infections.

In a single ward with abundant hospital resources, isolation and terminal disinfection measures have effectively controlled drug-resistant bacteria, including *A. baumannii* (6). However, ICUs are rarely designed as single-room ward models. Instead, they generally have multibed, large-room layouts. Patients in ICUs have extended stays and are not easily moved. Once hospital infections occur, isolation becomes ineffective, and disinfection serves as the sole measure to cut off transmission routes. This study aimed to explore the molecular link between multiple clusters of CRAB nosocomial infections in different years and to identify gaps in the current disinfection protocols for multibed ICUs in a hospital in Jiangsu Province, China.

A tertiary hospital in Jiangsu Province with approximately 4,000 beds was selected for this study. The emergency ICU consisted of 8 wards with 25 beds. *A. baumannii* strains were obtained from different aggregated cases in the emergency ICU during 2016–2021 from different aggregated cases (According to the guidelines for the control of healthcare-associated infection outbreaks WS/T 524-2016, the occurrence of 3 cases of hospital-acquired infections with the same pathogenic microorganism was regarded as an aggregated case) and the related ICU circumstances. Related pathogen surveillance was conducted from 2021 to 2024, following thorough terminal disinfection. Samples were collected from the sputum, blood, and wounds (Figure 1).

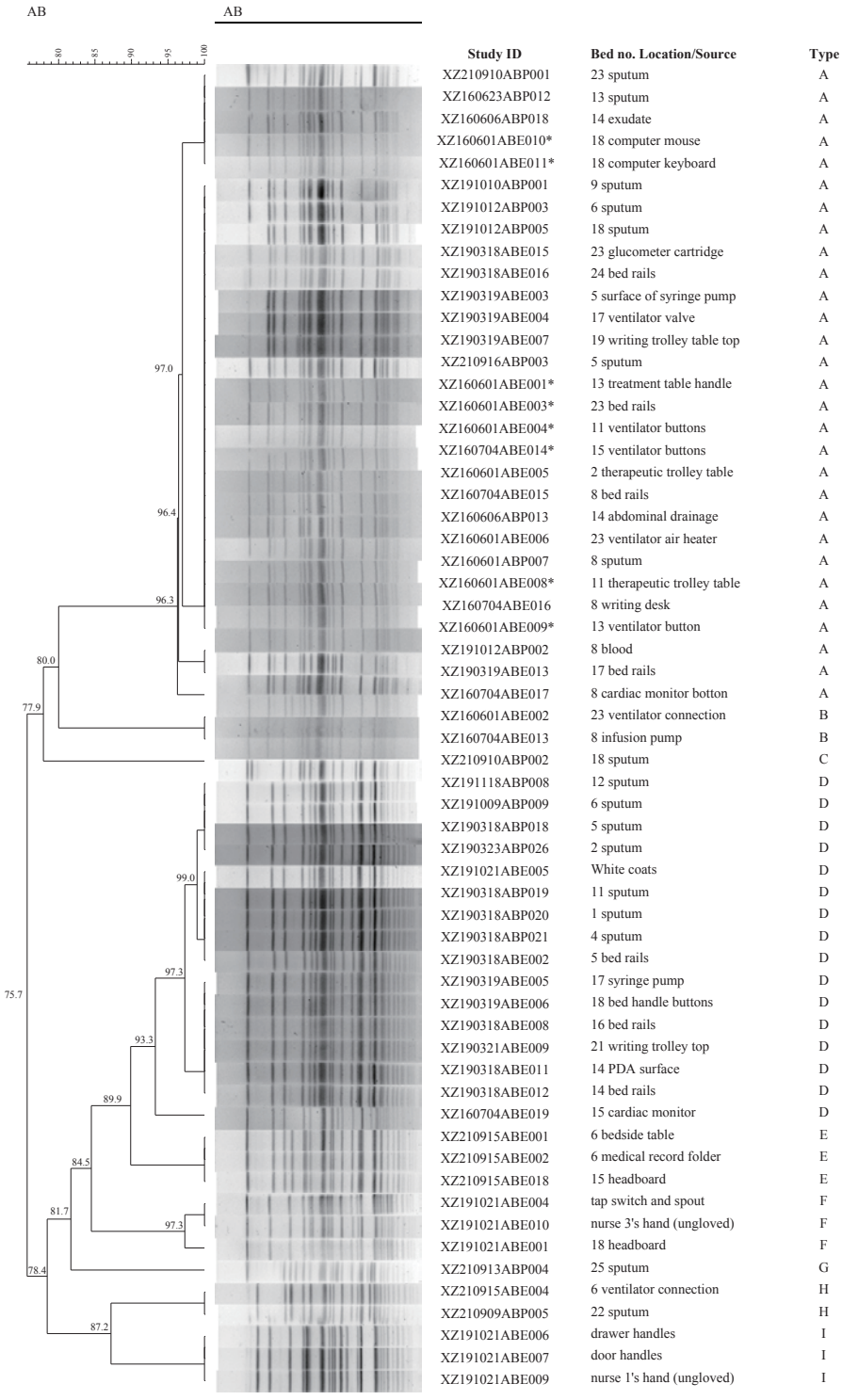
Environmental samples were collected by converting the high-contact surfaces of the ICU (bed rails, device controls/screens, charts, and call buttons) and general wards (door handles, carts, faucets, and sinks), nurses' stations (staff white coats, work surfaces, faucets/sinks, and drawer handles/phones), and dispensing and cleaning rooms (countertops, carts, faucets/sinks, door handles, and cleaning tools).

Bacterial isolates were initially purified on chromogenic medium plates. Species identification was performed using matrix-assisted laser desorption ionization time-of-flight mass spectrometry, calibrated with *Salmonella* H9812, and the results were analyzed using the Myla system. Antimicrobial susceptibility testing (AST) of *A. baumannii* utilized the VITEK2 system with GN AST-09 cards. Molecular typing of isolates was conducted via pulsed-field gel electrophoresis (PFGE) using the CHEF MAPPER™ system (BIO-RAD); DNA was digested by the *ApaI* restriction enzyme. The PFGE process was carried out at a voltage gradient of 6.0 V/cm, an angle of 120°, a temperature of 14 ℃, with pulse time ranging from 5–20 s, and lasted 18.5 h. PFGE gel images were analyzed using BioNumerics software. *A. baumannii* strains exhibiting more than 90% similarity based on Dice coefficients were classified as related strains.

A total of 5 aggregated clusters involving 19 patients were identified in 2016 (1st cluster, 3 cases), 2019 (2nd cluster, 4 cases; 3rd cluster, 5 cases; 4th cluster, 2 cases), and 2021 (5th cluster, 2 cases). From these clusters, 20 *A. baumannii* strains were isolated (2 strains were isolated from the patient's exudate and peritoneal drainage fluid, respectively) (Supplementary Table S1, available at https://weekly.chinacdc.cn/). In addition, 40 *A. baumannii* strains were isolated from the environmental samples (Supplementary Table S2, available at https://weekly.chinacdc.cn/). Among the 19 patients, 10 were co-infected with other pathogens, specifically *Klebsiella*.

The AST results for all isolates are presented in Supplementary Table S2. Among the 60 *A. baumannii* strains, 86.7% (52/60) were CRAB, including all 20 strains isolated from patients. Among the 52 strains exhibiting resistance to imipenem, 40 were resistant to meropenem and were recognized as CRAB.

PFGE was performed on 60 isolates, including 20 clinical and 40 environmental isolates. The 60 isolates were divided into 9 groups using a similarity cutoff of 90% (Figure 1). The largest group, A, comprised 29 isolates, including 10 from 9 patients (1st, 2nd, and 5th cluster patients in 2016, 2019, and 2021, respectively) and 19 from the relevant environment. The second largest group D had 16 isolates (3rd and 4th clusters in March and October-November in 2019, respectively) and the 9 related environmental isolates



Study ID	Bed no. Location/Source	Type
XZ210910ABP001	23 sputum	A
XZ160623ABP012	13 sputum	A
XZ160606ABP018	14 exudate	A
XZ160601ABE010*	18 computer mouse	A
XZ160601ABE011*	18 computer keyboard	A
XZ191010ABP001	9 sputum	A
XZ191012ABP003	6 sputum	A
XZ191012ABP005	18 sputum	A
XZ190318ABE015	23 glucometer cartridge	A
XZ190318ABE016	24 bed rails	A
XZ190319ABE003	5 surface of syringe pump	A
XZ190319ABE004	17 ventilator valve	A
XZ190319ABE007	19 writing trolley table top	A
XZ210916ABP003	5 sputum	A
XZ160601ABE001*	13 treatment table handle	A
XZ160601ABE003*	23 bed rails	A
XZ160601ABE004*	11 ventilator buttons	A
XZ160704ABE014*	15 ventilator buttons	A
XZ160601ABE005	2 therapeutic trolley table	A
XZ160704ABE015	8 bed rails	A
XZ160606ABP013	14 abdominal drainage	A
XZ160601ABE006	23 ventilator air heater	A
XZ160601ABP007	8 sputum	A
XZ160601ABE008*	11 therapeutic trolley table	A
XZ160704ABE016	8 writing desk	A
XZ160601ABE009*	13 ventilator button	A
XZ191012ABP002	8 blood	A
XZ190319ABE013	17 bed rails	A
XZ160704ABE017	8 cardiac monitor botton	A
XZ160601ABE002	23 ventilator connection	B
XZ160704ABE013	8 infusion pump	B
XZ210910ABP002	18 sputum	C
XZ191118ABP008	12 sputum	D
XZ191009ABP009	6 sputum	D
XZ190318ABP018	5 sputum	D
XZ190323ABP026	2 sputum	D
XZ191021ABE005	White coats	D
XZ190318ABP019	11 sputum	D
XZ190318ABP020	1 sputum	D
XZ190318ABP021	4 sputum	D
XZ190318ABE002	5 bed rails	D
XZ190319ABE005	17 syringe pump	D
XZ190319ABE006	18 bed handle buttons	D
XZ190318ABE008	16 bed rails	D
XZ190321ABE009	21 writing trolley top	D
XZ190318ABE011	14 PDA surface	D
XZ190318ABE012	14 bed rails	D
XZ160704ABE019	15 cardiac monitor	D
XZ210915ABE001	6 bedside table	E
XZ210915ABE002	6 medical record folder	E
XZ210915ABE018	15 headboard	E
XZ191021ABE004	tap switch and spout	F
XZ191021ABE010	nurse 3's hand (ungloved)	F
XZ191021ABE001	18 headboard	F
XZ210913ABP004	25 sputum	G
XZ210915ABE004	6 ventilator connection	H
XZ210909ABP005	22 sputum	H
XZ191021ABE006	drawer handles	I
XZ191021ABE007	door handles	I
XZ191021ABE009	nurse 1's hand (ungloved)	I

FIGURE 1. PFGE dendrogram of *A. baumannii* aggregated case groups by bed number, location, and source.
Note: 60 isolates (20 clinical and 40 environmental isolates) were included. The cluster analysis dendrogram is a molecular analysis performed by BioNumerics software to classify different *A. baumannii* strains based on band similarity, with a similarity value greater than 90% indicating the same origin. Study ID refers to the research identification numbers assigned in this study to *A. baumannii* strains isolated from patients or the environment. The Study IDs with an asterisk denote non-carbapenem *Acinetobacter baumannii* isolates. Bed No. location/source indicates the bed number and the type of patient specimen/environmental location from which the strain was isolated. Type denotes clusters identified by the software as strains of the same origin.
Abbreviation: AB=*A. baumannii=Acinetobacter baumannii*; PFGE=pulsed-field gel electrophoresis; ID=Identity Document.

(notably including a sample from 2016).

As confirmed by PFGE, the aggregated cases in June 2016 (3 cases) were identified as the same type of CRAB infection. Notably, 4 patients in 2019 (XZ191010ABP001, XZ191012ABP003, XZ191012ABP002, and XZ191012ABP005) and 2 patients in 2021 (XZ210910ABP001 and XZ210916ABP003) were also infected with the same type of CRAB as in 2016 (Figure 1). With regard to the locations of the patient and environmental samples, in 2016, the aggregated cases came from 2 multibed rooms (bed 8 in room 2 and beds 13 and 14 in room 3). The contaminated environmental area included the adjacent multibed room (*4*), the more distant double room (*7*), and the multibed room where the cases were located. The collected environmental area included 7 beds and 13 locations. In 2019, the aggregated cases were from 3 multibed rooms (bed 6 in room 1; beds 8 and 9 in room 2; and bed 18 in room 4). The contaminated environmental areas included the more distant double room 7 and multibed rooms where the cases were located. The collection area consisted of 5 beds and 6 locations. In 2021, the aggregated cases came from 2 multibed rooms (bed 5 in room 1 and bed 23 in room 7), and the environmental areas in these rooms were not contaminated (Figure 2A).

The second largest group of aggregated cases (group D), identified by PFGE, consisted of 5 cases in March 2019 and 2 cases from October to November 2019. These cases are homologous to those of the 2016 single-strain environmental samples. In March 2019, the cases came from beds 1, 2, 4, and 5 in room 1 and bed 11 in room 2, situated in 2 adjacent multiplexes (rooms 1 and 2). The contaminated environmental areas extended beyond the rooms where the patients stayed, encompassing adjacent multibed rooms 3 and 4 and a single room 5. Environmental samples were collected from 6 locations in the study area. During October-November, the aggregated cases came from bed 6 in room 1 and bed 12 in room 2. The contaminated environmental areas included nurse stations (Figure 2B).

DISCUSSION

In this retrospective study, molecular biology methods were successfully employed to trace multiple cases of clustered hospital-acquired infections in 2016 and beyond. These infections originated from both patients and the environment. Given that the study setting was an acute-care ICU, the hospital did not screen every admitted patient for multidrug-resistant bacteria and prior pathogen preservation from this ICU was not available. Consequently, determining whether the initial infections in 2016 were community-acquired or hospital-acquired/colonized was difficult. Using molecular biology analyses, subsequent cases (XZ160620ABP012 in 2016, 4 cases in 2019, and 2 cases in 2021) were judged to be molecular epidemiology-related and may be of the same origin. This retrospective analysis found that CRAB infections in ICUs in China shared similarities with the colonization and infection of VIM-producing *Pseudomonas aeruginosa* and NDM-producing *Enterobacteriaceae* in adults admitted to the ICU of a tertiary care hospital in Belgium between 2018 and 2022 (*7*).

PFGE confirmed that the aggregated cases in March 2019 (5 cases) and October–November 2019 (2 cases) were possibly caused by the same CRAB strain. According to the analysis of the sample collection time, the source of these 2 clustered cases was likely an environmental pathogen (XZ160704ABE019) collected from a 15-bed cardiac monitor in 2016. This study hypothesized that the buttons of cardiac monitors are an environmental reservoir of *A. baumannii*, along with the ventilators (7 samples) and syringe pumps (3 samples) used in this study. Such equipment with buttons is difficult to disinfect (*8*) and can facilitate the spread of infection through contact transmission, which can lead to associated transmission when healthcare workers fail to change gloves or perform hand hygiene after touching the equipment.

The transmission routes of the aggregated cases were analyzed. Although the study spanned a long time, this study was able to initially rule out the sharing of medical equipment as a possible transmission route by determining the source of the environmental samples. In contrast to previously published studies (*9*), *A. baumannii* environmental isolates were collected from only a few shared medical devices. A possible reason for this is that this study was conducted in the ICU, which generally has better-equipped facilities than the average department and does not require multiple patients to share medical devices. This study found that the only possibility for sharing was in the case of treatment carts, which are mobile medical devices (Figure 2).

A. baumannii bloodstream infections pose a serious risk to human health due to their high mortality rates (*10*). In the present study, infection was detected in only one blood sample (Supplementary Table S2).

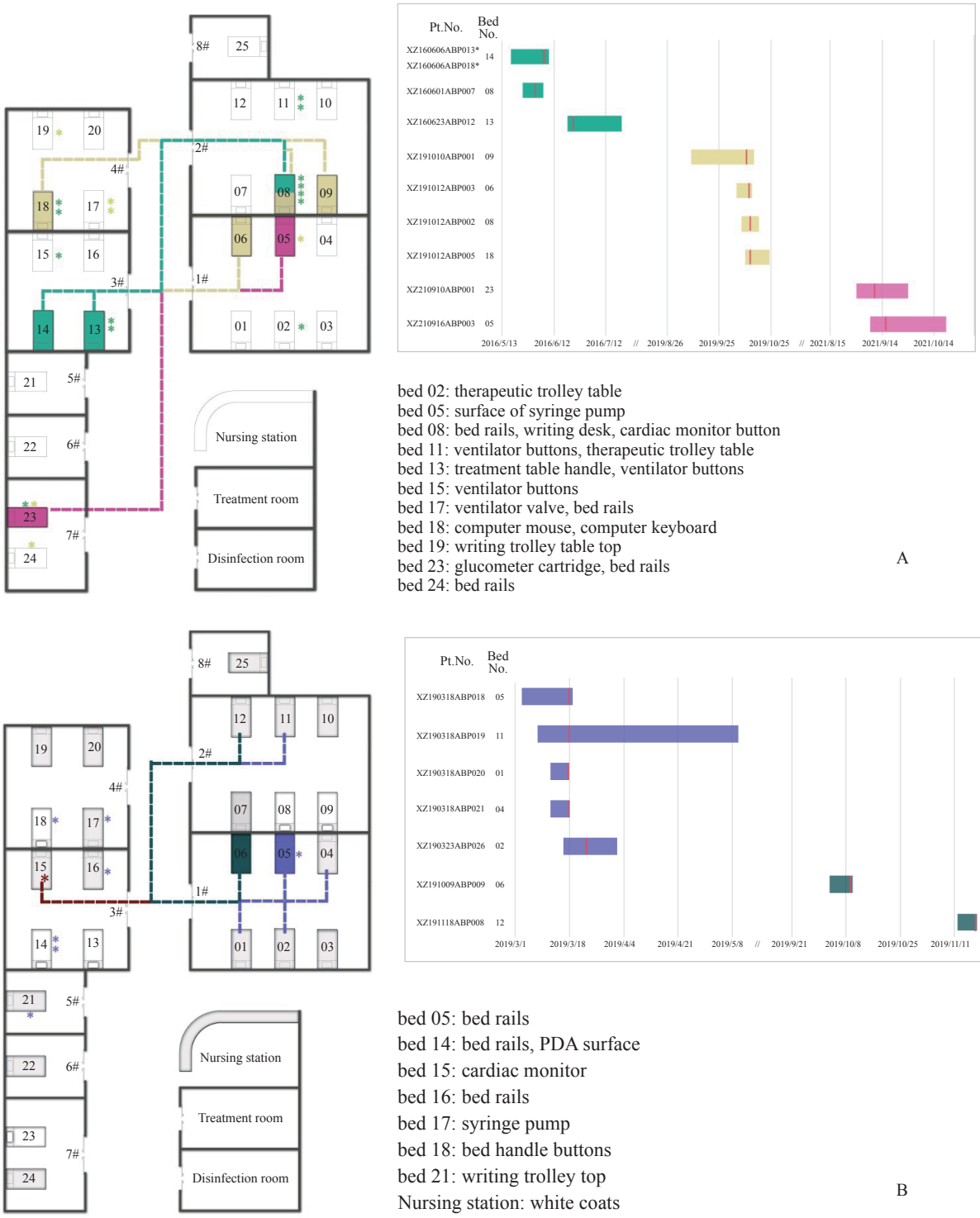


FIGURE 2. Summary of environmental positive samples, bed sites of HAI patients, and timeline of aggregated cases in the emergency ICU. (A) The 2016-2019-2021 aggregated cases. Light green, yellow, and magenta represent all samples collected in 2016, 2019, and 2021, respectively; (B) The 2016–2019 (March, Oct–Nov) aggregated cases.
Note: For B, brown, purple, and dark green represent environmental samples collected in 2016, and all samples collected in 2019 and 2021, respectively. All environmental sample collection locations are marked with asterisks on the map, using the same color as the bed positions of clinical cases at the same time, with textual annotations beside the map. Dashed lines represent molecular homology between different clinical cases. The sample collection times of clinical cases are indicated with red vertical lines on the timeline.
Abbreviation: HAI=healthcare-associated Infection; ICU=intensive care unit.

This finding is consistent with that reported by Kong et al. (*11*), who detected infections mainly in respiratory samples. This phenomenon may be related to the high number of mechanical ventilations in ICUs, which is a risk factor for hospital-acquired infections.

Drug sensitivity analysis revealed that all patient specimens were classified as CRAB. Physicians tend to use high-dose ampicillin-sulbactam to treat CRAB infections (*12*). Of the 20 patient samples, 1 (XZ160623ABP012) was resistant to ampicillin, sulbactam, and imipenem. This may lead to difficulties in treatment. However, 32 environmental samples were resistant to both antibiotics, which is another cause for concern. A strain of *A. baumannii* resistant to polymyxin B, imipenem, and meropenem was collected by a nurse. Polymyxins are effective treatments for CRAB (*13*). Bacteria that demonstrate simultaneous resistance to these drugs represent a major obstacle to treatment in the ICU. However, this strain was not detected in the aggregated cases.

In 2016, this study's authors implemented local disinfection measures in the ICU when they identified a short period of aggregated *A. baumannii* infection. No hospital-acquired infections with the same *A. baumannii* strain were recorded during the subsequent period. However, the retrospective discovery of molecularly linked cases in 2019 and 2021 suggests the presence of unidentified environmental reservoirs. Pathogenic microorganisms may still be present in 50% of patients after routine disinfection (*14*). Based on this evidence, the ICU transferred patients temporarily and instituted comprehensive terminal disinfection; no reappearance of relevant strains has been detected since then.

In conclusion, the data strongly imply that CRAB, which is responsible for aggregated cases of infections in ICUs, exhibits remarkable environmental persistence. This study observed that clustered cases occurring in different years over a five-year period may have close molecular epidemiological connections, suggesting that CRAB may pose a potential ongoing risk and could be one of the causes contributing to the occurrence of clustered infections in the ICU. Developing and implementing advanced disinfection techniques (such as vaporized or aerosolized hydrogen peroxide disinfection and the use of antimicrobial surface materials) and protocols tailored specifically to ICU settings are imperative for effectively mitigating CRAB transmission and reducing the incidence of hospital-acquired infections and outbreaks. Improved disinfection measures should target the unique characteristics of CRAB and the ICU environment, interrupt its transmission routes, and safeguard patient health.

This study has some limitations. Due to financial and human resource constraints, it did not follow up or analyze every case of hospital-acquired infection. Patient and environmental samples were collected only when aggregated cases were found in the hospitals. Therefore, the presence of individual cases among the aggregated cases was unclear. This study can only surmise from the molecular correlation that the subsequent aggregated cases might be from the aggregated cases and environmental samples collected in 2016. A clearer molecular epidemiological chain could be established with more comprehensive case tracking. However, the impact of this limitation is constrained, as the conclusions of this study are well supported by the molecular data from the aggregated cases that were collected.

Conflicts of interest: No conflicts of interest.

Ethical statements: Approved by Clinical Research and Ethics Committee of the tertiary hospital (approval no. XYFY2022-KL027-01).

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SUPPLEMENTARY MATERIAL

SUPPLEMENTARY TABLE 1. Clinical characteristics of CRAB infection in patients admitted to the ICU of a tertiary hospital.

Study ID	Bed no.	Age (year)/sex	Main underlying disease	Date of admission of ICU Date of discharge of ICU	Date of isolation	Other pathogens
XZ160601ABP007	08	76/M	Cerebral hemorrhage	May 25, 2016 June 6, 2016	June 1, 2016	CRKP
XZ160606ABP013 XZ160606ABP018	14	36/F	Multiple trauma	May 18, 2016 June 9, 2016	June 6, 2016	CRKP
XZ160620ABP012	13	53/F	Cerebral infarction	June 20, 2016 July 21, 2016	June 23, 2016	/
XZ190318ABP018	05	29/M	Brain stem hemorrhage	Mar 3, 2019 Mar 19, 2019	Mar 18, 2019	/
XZ190318ABP019	11	69/M	Multiple trauma	Mar 8, 2019 May 10, 2019	Mar 18, 2019	CRKP
XZ190318ABP020	01	69/F	Left basal ganglia hemorrhage	Mar 12, 2019 Mar 18, 2019	Mar 18, 2019	/
XZ190318ABP021	04	51/F	Postoperative cerebral hemorrhage	Mar 12, 2019 Mar 18, 2019	Mar 18, 2019	*Klebsiella Pneumoniae*
XZ190323ABP026	02	55/M	Multiple trauma	Mar 16, 2019 Apr l2, 2019	Mar 23, 2019	/
XZ191009ABP009	06	40/F	Middle cerebral artery aneurysm	Oct 3, 2019 Oct 10, 2019	Oct 9, 2019	/
XZ191010ABP001	09	45/M	Cerebral hemorrhage	Sep 9, 2019 Oct 15, 2019	Oct 10, 2019	CRKP
XZ191012ABP002	08	30/M	Diabetic ketoacidosis	Oct 8, 2019 Oct 18, 2019	Oct 12, 2019	CRKP
XZ191012ABP003	06	66/M	Upper gastrointestinal hemorrhage	Oct 5, 2019 Oct 14, 2019	Oct 12, 2019	/
XZ191012ABP005	18	48/F	Left cerebellar cerebral hemorrhage	Oct 10, 2019 Oct 24, 2019	Oct 12, 2019	CRKP
XZ191118ABP008	12	76/M	Multiple cerebral contusion	Nov 12, 2019 Nov 18, 2019	Nov 18, 2019	CRKP
XZ210909ABP005	22	79/M	Meningeoma	Sep 3, 2021 Sep 17, 2021	Sep 9, 2021	CRKP
XZ210910ABP001	23	64/M	Acute severe pancreatitis	Aug 30, 2021 Sep 29, 2021	Sep 10, 2021	/
XZ210910ABP002	18	80/M	Bilateral posterior communicating artery aneurysm	Aug 31, 2021 Sep 29, 2021	Sep 10, 2021	/
XZ210913ABP004	25	75/M	Type I respiratory failure	Sep 9, 2021 Sep 18, 2021	Sep 13, 2021	/
XZ210916ABP003	05	58/M	Intracranial hemorrhage(non-traumatic)	Sep 7, 2021 Oct 21, 2021	Sep 16, 2021	*Klebsiella Pneumoniae*

Abbreviation: CRAB=carbapenem-resistant *Acinetobacter baumannii*; CRKP=carbapenem-resistant *Klebsiella pneumoniae*; ICU=intensive care unit.

SUPPLEMENTARY TABLE S2. Summary of antibiotic susceptibility testing of *A. baumannii* clinical and environmental isolates from emergency ICU.

Study ID	Bed no. location/source	Drug resistance
XZ210910ABP001	23 sputum	TZA CTT CAZ FEP AZT IPM CIP LVX SXT TOB AMC DOR DOX MEM MXF TE TIC CXM SCF ZOX CTX CSSS PIP CPD NOR TIM
XZ160623ABP012	13 sputum	AMP SAM CRO FEP IPM GM TOB CIP LVX NIT SXT FOX AMC
XZ160606ABP018	14 exudate	AMP TZP CZ CRO FEP IPM GM TOB CIP LVX NIT SXT FOX AMC
XZ160601ABE010	18 computer mouse	AMP CZ CTT NIT
XZ160601ABE011	18 computer keyboard	AMP CZ CTT NIT
XZ191010ABP001	9 sputum	TZP CTT CAZ FEP AZT IPM CIP LVX SXT GM AMC DOR DOX MEM MXF TE CXM ZOX CTX CSSS PIP CPD
XZ191012ABP003	6 sputum	SAM CTT CAZ AZT IPM CIP LVX SXT TOB DOR MEM MXF TIC CXM SCF ZOX CTX CSSS PIP CPD
XZ191012ABP005	18 sputum	TZP CTT CAZ AZT IPM CIP LVX SXT GM AMC DOR MEM MXF CXM SCF ZOX CTX CSSS PIP CPD
XZ190318ABE015	23 glucometer cartridge	SAM TZP CAZ IPM GM CIP SXT MEM CTX AMK
XZ190318ABE016	24 bed rails	SAM TZP CAZ FEP IPM GM CIP LVX SXT MEM CTX AMK
XZ190319ABE003	5 surface of syringe pump	SAM TZP CAZ IPM GM CIP SXT MEM CTX AMK
XZ190319ABE004	17 ventilator valve	SAM TZP CAZ IPM GM CIP SXT MEM CTX AMK
XZ190319ABE007	19 writing trolley table top	SAM TZP CAZ FEP IPM GM CIP LVX SXT MEM CTX AMK
XZ210916ABP003	5 sputum	TAP CTT CAZ AZT IPM CIP LVX SXT TOB AMC DOR DOX MEM MXF TE TIC CXM ZOX CTX CSSS PIP CPD NOR TIM
XZ160601ABE001	13 treatment table handle	AMP SAM TZP CZ CTT CAZ CRO FEP AZT GM TOB CIP NIT SXT
XZ160601ABE003	23 bed rails	AMP SAM TZP CZ CTT CAZ CRO FEP AZT GM TOB CIP NIT SXT
XZ160601ABE004	11 ventilator buttons	AMP SAM TZP CZ CTT CAZ CRO FEP AZT GM TOB CIP NIT SXT
XZ160704ABE014	15 ventilator buttons	AMP SAM TZP CZ CTT CAZ CRO FEP AZT GM TOB CIP NIT SXT
XZ160601ABE005	2 therapeutic trolley table	AMP TZP CZ CTT CAZ CRO FEP AZT IPM GM TOB CIP LVX NIT SXT
XZ160704ABE015	8 bed rails	AMP SAM TZP CZ CTT CAZ CRO FEP AZT IPM GM TOB CIP NIT
XZ160606ABP013	14 abdominal drainage	AMP TZP CZ CRO FEP IPM GM TOB CIP NIT SXT AML FOX
XZ160601ABE006	23 ventilator air heater	AMP SAM TZP CZ CTT CAZ CRO FEP AZT IPM GM TOB CIP NIT SXT
XZ160601ABP007	8 sputum	AMP TZP CZ CRO FEP IPM GM TOB CIP LVX NIT SXT AML FOX
XZ160601ABE008	11 therapeutic trolley table	AMP SAM TZP CZ CTT CAZ CRO FEP AZT GM TOB CIP NIT SXT
XZ160704ABE016	8 writing desk	AMP SAM TZP CZ CTT CAZ CRO FEP AZT IPM GM TOB CIP NIT SXT
XZ160601ABE009	13 ventilator button	AMP SAM TZP CZ CTT CAZ CRO FEP AZT GM TOB CIP NIT SXT
XZ191012ABP002	8 blood	TZP CTT CAZ FEP AZT IPM CIP LVX SXT GM AMC DOR MEM MXF CXM SCF ZOX CTX CSSS PIP CPD
XZ190319ABE013	17 bed rails	SAM TZP CAZ IPM GM CIP LVX SXT MEM CTX AMK
XZ160704ABE017	8 cardiac monitor button	AMP SAM TZP CZ CTT CAZ CRO FEP AZT IPM GM TOB CIP LVX NIT SXT
XZ160601ABE002	23 ventilator connection	AMP SAM TZP CZ CTT CAZ CRO FEP AZT IPM GM TOB CIP NIT SXT
XZ160704ABE013	8 infusion pump	AMP SAM TZP CZ CTT CAZ CRO FEP AZT IPM GM TOB CIP NIT SXT
XZ210910ABP002	18 sputum	TZP CTT CAZ FEP AZT IPM CIP LVX SXT TOB AMC DOR DOX MEM MXF TE TIC CXM SCF ZOX CTX CSSS PIP CPD NOR TIM
XZ191118ABP008	12 sputum	TZP CTT CAZ FEP AZT IPM CIP SXT TOB AMC DOR DOX MEM MXF TE CXM ZOX CTX CSSS PIP CPD
XZ191009ABP009	6 sputum	TZP CAZ FEP AZT IPM CIP LVX MEM MIN SCF DOX
XZ190318ABP018	5 sputum	TZP CTT CAZ FEP AZT IPM CIP SXT DOR DOX MEM MXF TE TIC CXM SCF ZOX CTX CSSS PIP CPD
XZ190323ABP026	2 sputum	TZP CTT CAZ AZT IPM CIP LVX SXT TOB DOR MEM MXF TIC CXM SCF ZOX CTX CSSS PIP CPD
XZ191021ABE005	white coats	SAM TZP CAZ FEP IPM GM CIP SXT MEM SCF CTX AMK
XZ190318ABP019	11 sputum	TZP CTT CAZ FEP AZT IPM CIP SXT TOB DOR DOX MEM TE TIC CXM SCF ZOX CTX CSSS PIP CPD

Continued

Study ID	Bed no. location/source	Drug resistance
XZ190318ABP020	1 sputum	TZP CTT CAZ FEP AZT IPM CIP LVX SXT TOB DOR DOX MEM MXF TE TIC CXM SCF ZOX CTX CSSS PIP CPD
XZ190318ABP021	4 sputum	TZP CTT CAZ FEP AZT IPM CIP SXT TOB DOR DOX MEM MXF TE TIC CXM SCF ZOX CTX CSSS PIP CPD
XZ190318ABE002	5 bed rails	SAM TZP CAZ FEP IPM GM CIP SXT MEM SCF CTX AMK
XZ190319ABE005	17 syringe pump	SAM TZP CAZ FEP IPM GM CIP SXT MEM SCF CTX AMK
XZ190319ABE006	18 bed handle buttons	SAM TZP CAZ FEP IPM GM CIP SXT MEM SCF CTX AMK
XZ190318ABE008	16 bed rails	SAM TZP CAZ FEP IPM GM CIP SXT MEM SCF CTX AMK
XZ190321ABE009	21 writing trolley top	SAM TZP CAZ FEP IPM GM CIP SXT MEM SCF CTX AMK
XZ190318ABE011	14 PDA surface	SAM TZP CAZ FEP IPM GM CIP LVX SXT MEM SCF CTX AMK
XZ190318ABE012	14 bed rails	SAM TZP CAZ FEP IPM GM CIP SXT MEM SCF CTX AMK
XZ160704ABE019	15 cardiac monitor	AMP SAM TZP CZ CTT CAZ CRO FEP AZT IPM CIP NIT
XZ210915ABE001	6 bedside table	SAM TZP CAZ FEP IPM GM CIP LVX SXT MEM SCF CTX AMK
XZ210915ABE002	6 medical record folde	SAM TZP CAZ FEP IPM GM CIP LVX SXT MEM SCF CTX AMK
XZ210915ABE018	15 headboard	SAM TZP CAZ FEP IPM GM CIP LVX SXT MEM SCF CTX AMK
XZ191021ABE004	tap switch and spout	SAM TZP CAZ IPM GM CIP SXT MEM CTX AMK
XZ191021ABE010	nurse 3's hand (ungloved)	SAM TZP CAZ FEP IPM GM CIP LVX SXT PB MEM SCF CTX AMK
XZ191021ABE001	18 headboard	SAM TZP CAZ IPM GM CIP SXT MEM CTX AMK
XZ210913ABP004	25 sputum	TZP CTT CAZ FEP AZT IPM CIP LVX SXT TOB AMC DOR DOX MEM MXF TE TIC CXM SCF ZOX CTX CSSS PIP CPD NOR TIM
XZ210915ABE004	6 ventilator connection	SAM TZP CAZ IPM GM CIP LVX SXT MEM CTX
XZ210909ABP005	22 sputum	TZP CTT CAZ FEP AZT IPM CIP LVX TOB AMC DOR DOX MEM MXF TE TIC CXM ZOX CTX CSSS PIP CPD NOR TIM
XZ191021ABE006	drawer handles	SAM TZP CAZ FEP IPM GM CIP SXT MEM CTX AMK
XZ191021ABE007	door handles	SAM TZP CAZ FEP IPM GM CIP LVX SXT MEM SCF CTX AMK
XZ191021ABE009	nurse 1's hand (ungloved)	SAM TZP CAZ FEP IPM GM CIP LVX SXT MEM SCF CTX AMK

Abbreviation: AMP=ampicillin; SAM=ampicillin-sulbactam; TZP=piperacillin-tazobactam; CZ=cefazolin; CTT=cefotetan; CAZ=ceftazidime; CRO=ceftriaxone; FEP=cefepime; AZT=aztreonam; IPM=imipenem; GM=gentamicin; TOB=tobramycin; CIP=ciprofloxacin; LVX=levofloxaci; NIT=nitrofurantoin; SXT=trimethoprim-sulfamethoxazole; AML=amoxicillin; TGC=tigecycline; FOX=cefoxitin; AMC=amoxicillin-clavulantic acid; DOR=doripenem; DOX=doxycycline; PB=polymyxin B; MEM=meropenem; MIN=minocycline; MXF=moxifloxacin; TE=tetracycline; TIC=ticarcillin; CXM=cefuroxime; SCF=cefoperazone-sulbactam; ZOX=ceftizoxime; CTX=cefotaxime; CSSS=cefoperazone Sodium and Sulbactam Sodium; PIP=piperacillin; DOX=doxycycline; CPD=cefpodoxime; AMK=amikacin; NOR=norfloxacin; TIM=ticarcillin-clavulnic acid.