

ORIGINAL RESEARCH ARTICLE

Beyond the pathogen: Tracing healthcare worker-mediated cross-transmission through real-time infection prevention surveillance and quality improvement

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Abstract

Transmission of carbapenem-resistant *Acinetobacter baumannii* (CRAB) can be facilitated by lapses in infection prevention and control practices among healthcare workers, underscoring the need for proactive, real-time surveillance. In November 2025, a CRAB outbreak occurred at a cardiac tertiary care center in Karachi, Pakistan, involving seven patients who developed central line-associated bloodstream infections and hospital-acquired pneumonia. Following an Infection Control Committee meeting, a one-month intensive surveillance program was implemented from December 1–31, 2025, deploying a senior infection control nurse exclusively during evening shifts to observe, document, and provide immediate corrective teaching across all clinical areas, including intensive care, coronary care, operating rooms, and dialysis units. Over four weeks, 309 spot teaching sessions were conducted with 64, 85, 73, and 87 healthcare workers, respectively. Persistent systemic non-compliance was identified across multiple domains, including incorrect use of personal protective equipment, particularly in operating rooms and during isolation precautions; improper disposal of sharps and biomedical waste; delayed initiation of isolation; critical reprocessing failures involving bougie catheters and oxygen bottles; and environmental hygiene deficits, including rusted equipment. The surveillance uncovered a critical lack of standardization in bougie catheter classification across units and hazardous pre-transport practices, including sending contaminated items to central sterile processing. Following real-time corrective interventions and escalation of systemic issues to management, the outbreak was successfully contained with no new CRAB cases reported during or after the surveillance period. This experience demonstrates that targeted, proactive infection-prevention surveillance during high-risk evening shifts, combined with immediate educational reinforcement, can effectively identify and address latent systemic failures and behavioral non-compliance that might be overlooked during routine daytime audits, thereby providing a practical framework for outbreak mitigation in resource-constrained settings.

Keywords: Carbapenem-resistant *Acinetobacter baumannii*; Outbreak management; Infection prevention and control; Healthcare-associated infections; Surveillance; Quality improvement; Intensive care unit; Coronary care unit

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1. Introduction

Healthcare-associated infections (HAIs) caused by multidrug-resistant organisms (MDROs) represent a formidable challenge to global public health, burdening healthcare systems with increased morbidity, mortality, and economic costs.^{1,2} Among these, carbapenem-resistant *Acinetobacter baumannii* (CRAB) stands out for its remarkable capacity for environmental persistence, propensity for nosocomial transmission, and association with severe infections in critically ill patients, particularly those in intensive care units (ICUs) and undergoing invasive procedures.^{3,4} Outbreaks of CRAB are notoriously difficult to contain because CRAB is resistant to most first-line antibiotics and can colonize both patients and the hospital environment.⁴

Recent systematic reviews and meta-analyses have consolidated the evidence on CRAB outbreak management, highlighting that multifaceted infection prevention and control (IPC) interventions remain the cornerstone of containment. Bundled IPC interventions, including enhanced environmental cleaning, reinforcement of hand hygiene, contact precautions, and active surveillance cultures, have been consistently associated with substantial reductions in CRAB transmission and acquisition in ICU settings.⁵ Furthermore, delayed recognition of transmission, lapses in contact precautions, and inadequate environmental decontamination are recurring contributors to healthcare outbreaks.⁶ These findings underscore that while the pathogen's intrinsic resistance and environmental persistence are formidable, the majority of outbreaks are driven by modifiable human and system factors that can be addressed through targeted surveillance and education.

However, the evidence base has notable gaps. Most published studies focus on outbreak investigations in high-income settings with substantial IPC resources, leaving a paucity of data from low- and middle-income countries where healthcare systems face unique challenges, including resource constraints, higher patient-to-staff ratios, and competing clinical priorities. Furthermore, few studies have specifically examined the impact of surveillance outside routine administrative hours, despite growing recognition that IPC compliance may vary significantly by shift. These studies have shown that hand hygiene adherence is significantly lower during night shifts than during daytime, suggesting that targeted monitoring and reinforcement during evening and nighttime hours may substantially improve overall compliance.^{7,8} Our study addresses these gaps by describing a pragmatic, resource-appropriate intervention in a cardiac tertiary care center in Pakistan, focusing on evening-shift surveillance and real-time corrective feedback.

Outbreak management in tertiary care hospitals requires a multifaceted approach rooted in robust IPC principles. Core strategies include active surveillance, strict adherence to hand hygiene and contact precautions, effective environmental decontamination, and antimicrobial stewardship.⁹ However, the consistent application of these measures is often impeded by human factors, workflow pressures, and variability in compliance across different shifts and departments.^{10,11} Notably, lapses in IPC protocols may be more prevalent during evening and night shifts, periods often characterized by reduced supervisory presence and higher staff-to-patient ratios.^{12,13}

The pervasive threat of CRAB is amplified by a complex interplay between microbial virulence, environmental contamination, and entrenched human factors within hospital workflows. While the pathogen's ability to survive for extended periods on dry surfaces, ranging from bed rails to ventilators, creates a persistent environmental reservoir, breaches in fundamental IPC practices by healthcare workers most often facilitate transmission from this reservoir to susceptible patients.¹⁴ This human element transforms a latent risk into an active outbreak. The challenges are systemic and behavioral: cognitive overload in high-acuity settings leads to missed hand hygiene moments; habitual shortcuts become normalized, especially during periods of high workload or fatigue; and a pervasive "know-do" gap exists, where theoretical knowledge of protocols fails to translate into consistent practice.^{15–17} This gap is frequently widened by systemic failures, such as poorly accessible alcohol-based hand rub dispensers, shortages of appropriately sized personal protective equipment (PPE), or confusing waste segregation guidelines. Furthermore, the social and hierarchical culture within clinical units can emphatically enable or inhibit compliance. Therefore, understanding and interrupting CRAB transmission requires moving beyond a purely microbiological or environmental focus to address these intricate human and organizational determinants.¹⁷

In this context, dynamic, proactive, and contextual surveillance strategies become critical. Conventional IPC audits, often scheduled during daytime administrative hours, may fail to capture the true landscape of compliance, particularly during evening and night shifts, when supervisory oversight diminishes, and workflow pressures differ.^{7,12} Hence, reactive investigations after an outbreak are often less beneficial and represent a failure of compliance. Instead, a paradigm shift towards proactive, real-time surveillance is needed to identify and correct latent failures before they coalesce into transmission events. This involves deploying IPC expertise directly in the clinical environment across all shifts to observe practice in real time,

provide immediate feedback, and gather authentic data on barriers to compliance. The “spot teaching” or immediate correction model is particularly potent, as it delivers just-in-time education at the exact moment and location of the error, thereby maximizing relevance and impact.^{18,19} This strategy aims to reshape both individual behavior and unit culture through consistent, non-punitive reinforcement. By focusing on high-risk periods and employing direct observational feedback, healthcare institutions can shift from a cycle of post-outbreak investigation to a model of continuous pre-emptive risk mitigation, building a more resilient defense against outbreaks.

In November 2025, a cardiac tertiary care center in Karachi, Pakistan, identified a cluster of CRAB infections. Seven patients were affected, who developed central line-associated bloodstream infections (CLABSI) and hospital-acquired pneumonia (HAP), raising immediate concern for a potential outbreak driven by healthcare worker-mediated cross-transmission. An initial investigation, discussed in an Infection Control Committee (ICC) meeting on November 27, 2025, excluded contaminated pharmaceuticals or a single environmental source, pointing instead towards breaches in fundamental IPC practices as the potential driver of the outbreak. In response, a one-month intensive IPC surveillance initiative was launched from December 1–31, 2025, with a novel focus on deploying a senior infection control nurse (ICN) exclusively during the evening shift to conduct real-time observations and interventions. This study details the findings of that surveillance, the interventions undertaken, and the outcomes achieved, providing a practical framework for mitigating similar outbreaks.

2. Methods

2.1. Study design and setting

This was a prospective, observational quality improvement study conducted at the Tabba Heart Institute, Karachi, Pakistan, over one month, from December 1–31, 2025. The intervention was triggered by an investigation into a CRAB outbreak in November 2025. The institute is a specialized tertiary cardiac center providing comprehensive cardiology and cardiac surgery care, with a 12-bed ICU, a 12-bed coronary care unit (CCU), three operating rooms (ORs), a catheterization lab, and both step-down and general wards.

2.2. Outbreak investigation and Infection Control Committee meeting

The initial outbreak involved seven patients with CRAB isolates ($n = 3$ CLABSI and $n = 4$ HAP). A comprehensive outbreak investigation was undertaken from November 21–25, 2025. This included environmental cultures from

ICU, CCU, OR, and other critical areas; cultures of high-use medications; hand cultures from 10 ICU and OR staff members; and cultures of water and central line sleeve kits. All investigations returned negative results. The findings were presented at an ICC meeting on November 27, 2025, chaired by the medical director and attended by heads of clinical departments, nursing, pharmacy, and quality assurance. The consensus concluded that the outbreak was primarily due to healthcare worker-mediated cross-transmission linked to lapses in IPC practices, necessitating immediate reinforcement.

The outbreak investigation strategy was guided by established epidemiological principles for HAI outbreak detection and management. Case definitions were based on the Centers for Disease Control and Prevention's (CDC) National Healthcare Safety Network (NHSN) criteria for CLABSI and HAP, as these were the clinical presentations observed in the affected patients.^{20,21} For CRAB identification, clinical isolates were obtained from blood and respiratory specimens submitted for routine culture and antimicrobial susceptibility testing. Antimicrobial susceptibility testing was performed using the Kirby–Bauer disk diffusion method, and clinical breakpoints were interpreted in accordance with the Clinical and Laboratory Standards Institute's guidelines.²² Environmental and pharmaceutical samples were cultured using standard microbiological methods to exclude a common environmental or product source. This investigation protocol was consistent with the World Health Organization (WHO) and CDC guidelines for outbreak investigation, which recommend a stepwise approach including case definition, case finding, descriptive epidemiology, and environmental sampling, with molecular confirmation where resources permit.^{23,24}

Molecular testing, including whole-genome sequencing or pulsed-field gel electrophoresis, was not performed due to resource constraints and limited availability of such technologies in our setting. However, to assess potential relatedness between the seven clinical isolates, we compared their antimicrobial susceptibility patterns. Although antibiograms cannot establish clonality, comparison of susceptibility profiles has been widely used as an adjunct epidemiological tool during outbreak investigations, particularly when molecular typing is unavailable or not immediately accessible. Subsequent molecular typing remains the preferred method for confirming isolate-relatedness.^{25–27}

All seven isolates demonstrated identical or highly similar resistance profiles, i.e., non-susceptibility to carbapenems and other beta-lactams, with susceptibility patterns consistent with CRAB, suggesting they may

represent a common strain or closely related strains. While this does not provide definitive proof of clonality, the temporal clustering, identical resistance patterns, and epidemiological links between the affected patients provided sufficient evidence to investigate a common transmission pathway.

2.3. Outbreak case definitions

Case definitions for outbreak patients were based on CDC's NHSN surveillance definitions for HAIs.^{20,21} A case of CLABSI was defined as a laboratory-confirmed bloodstream infection in a patient with a central line at the time of or within 48 h prior to the positive culture, with the infection not related to an infection at another site. HAP was defined as pneumonia occurring 48 h or more after admission, not incubating at the time of hospitalization, with clinical signs such as fever, leukocytosis, and purulent sputum, and radiographic evidence of a new or progressive infiltrate consistent with pneumonia, and a positive respiratory culture for CRAB. Inclusion criteria for the outbreak case series were (i) patients admitted to the ICU or CCU at Tabbā Heart Institute during November 2025, (ii) clinical and microbiological confirmation of CRAB infection with onset during the outbreak period, and (iii) meeting CDC's NHSN criteria for CLABSI or HAP. Exclusion criteria included (i) patients with CRAB colonization without clinical infection, (ii) patients with CRAB infection but with onset prior to the outbreak period or after the outbreak control measures were implemented, and (iii) patients with infections due to other pathogens. The seven patients included in the outbreak all met the inclusion criteria. Case finding was conducted by reviewing microbiology laboratory records and line lists of patients with positive CRAB cultures from clinical specimens, followed by clinical chart review to confirm infection and meet the CDC's NHSN definitions.

2.4. Intervention: Enhanced evening shift infection prevention and control surveillance

In accordance with the ICC recommendations, the IPC department implemented an intensive surveillance program. The key operational change was assigning a senior ICN to work the evening shift through December 1–31, 2025. This shift was strategically chosen based on the hypothesis that IPC compliance decreases outside of routine administrative and morning rounds.

The surveillance followed a structured protocol, beginning with daily, unannounced rounds conducted by the ICN in all clinical and support areas. These areas included the Emergency Room, Step-Down Unit, Private Wing, High Dependency Unit, CCU, ICU, General Wards, ORs, Cardiac Catheterization Lab and Central Sterile

Supply Department. During these rounds, observations were documented against five core IPC domains using an observational checklist. The domains were (i) hand hygiene, focusing on compliance with WHO's "Five Moments for Hand Hygiene"; (ii) PPE, assessing the correct use of gloves, gowns, masks, and eye protection; (iii) transmission-based precautions, evaluating the timely initiation and maintenance of isolation protocols; (iv) environmental hygiene and waste management, checking cleanliness and proper waste segregation; and (v) reprocessing of medical devices, verifying compliance with cleaning, disinfection, and sterilization protocols for reusable items.

Upon identifying a breach, the ICN provided immediate, on-the-spot education to the involved healthcare worker (spot teaching). This intervention involved explaining the correct protocol, its rationale, and the associated infection risk. The staff member's name, department, and the teaching topic were then logged in a dedicated register. For significant or recurrent breaches, an escalation process was followed, with issues reported simultaneously to the respective team leaders, unit managers, and department heads. Finally, a comprehensive weekly report compiling all observations, corrective actions, and preventive measures was generated to ensure systematic feedback and accountability.

2.5. Surveillance and intervention framework

Our surveillance and intervention framework was guided by established IPC principles, particularly WHO's "Minimum Requirements for Infection Prevention and Control" and the CDC's "Core Infection Prevention and Control Practices for Safe Healthcare Delivery in All Settings."^{9,28} The WHO framework emphasizes that effective IPC programs require dedicated trained personnel, active surveillance, regular monitoring with feedback, and the integration of education into daily practice. Our approach operationalized these principles by deploying a senior ICN specifically during evening shifts, a period identified as high-risk due to reduced supervisory oversight, to conduct systematic observations across all clinical areas. The ICN utilized a structured observational checklist adapted from the WHO Hand Hygiene Observation Tool and WHO Infection Prevention and Control Assessment Framework.^{29,30} The checklist documented breaches in hand hygiene, PPE use, transmission-based precautions, environmental hygiene, and medical device reprocessing, with immediate corrective teaching provided at the point of care. This methodology aligns with the multimodal strategy endorsed by the WHO and CDC, which includes system change, training and education, monitoring and feedback, workplace reminders, and institutional safety climate.^{9,31,32} The addition of immediate spot teaching as

an intervention component is consistent with the “just-in-time training” approach described by Sickbert-Bennett *et al.*¹⁸ and Owen *et al.*¹⁹, which has been shown to improve immediate compliance and reinforce correct practices in clinical settings.

2.6. Data collection and analysis

Data were collected daily using a standardized surveillance form. Qualitative data consisted of detailed descriptions of non-compliant events, the units involved, and the staff addressed. Quantitative data included the number of spot teaching sessions conducted per week. Data from the surveillance forms, spot teaching registers, and summary reports were synthesized to identify patterns, recurrent themes, and systemic weaknesses. The primary outcome measure was the containment of the CRAB outbreak, defined as the absence of new clinically or microbiologically confirmed CRAB cases among ICU/CCU patients with onset during the three-month post-intervention surveillance period.

3. Results

3.1. Spot teaching interventions

The senior ICN conducted 309 spot teaching sessions over the four-week period, engaging a wide range of healthcare workers, including nurses, technicians, physicians, housekeeping staff, and security personnel. The week-wise review showed variations in the number of engagements: 64 in the first week, 85 in the second, 73 in the third, and 87 in the fourth week (Table 1). This trend suggests that both increased surveillance activity and a persistently high level of non-compliance requiring continuous intervention are simultaneously true; the surveillance activity was capturing a pre-existing high level of non-compliance that might otherwise have gone undetected. Moreover, because these engagements involved different healthcare workers across various clinical areas each week, with minimal repetition of the same individuals, they indicate a widespread need for education rather than a small group of persistent offenders.

3.2. Categorization of major infection prevention and control breaches

To systematically interpret the breadth and recurrence of observed non-compliant practices, IPC breaches identified during enhanced surveillance were thematically grouped into major categories. This categorization was undertaken to highlight dominant patterns of risk, distinguish behavioral from system-level deficiencies, and facilitate targeted corrective interventions. The resulting framework reflects recurring operational vulnerabilities across clinical and support areas and provides a structured basis for

prioritizing institutional efforts to strengthen IPC. Four major breach categories were identified.

Table 1. Weekly distribution of spot teaching sessions conducted during enhanced evening shift infection prevention and control surveillance (December 2025)

Week	Number of healthcare worker teaching encounters	Cumulative total
1 st week	64	64
2 nd week	85	149
3 rd week	73	222
4 th week	87	309

Note: The values represent the number of healthcare worker teaching encounters per week, not unique individuals; therefore, the same healthcare worker could have been counted more than once across different weeks.

3.2.1. Non-compliance with personal protective equipment and isolation precautions

This was the most frequently observed IPC lapse (Figure 1). Staff were found not wearing gowns, masks, or gloves when managing patients on contact or droplet precautions. For instance, on December 2, 2025, staff and a patient attendant mobilized a contact precaution patient without donning gowns or masks (Table 2). In the OR, anesthesiologists were observed performing intubations and intravenous cannulations without gowns while wearing jewelry such as rings and chains, a direct breach of aseptic principles. Furthermore, delays in implementing isolation for suspected influenza and tuberculosis patients, and the absence of appropriate precaution signage on doors, were repeatedly noted, increasing the risk of cross-transmission.

3.2.2. Inadequate management of biomedical waste and sharps

Improper waste segregation and disposal posed a significant hazard (Figure 1). Sharps were found on floors, in green general waste bins, and even inside linen hampers. Overfilled sharps containers and red bags of infectious waste were common. Dialysis circuits, which are infectious waste, were incorrectly disposed of in general waste bins. These practices contravene standard biomedical waste management protocols and expose staff and patients to bloodborne pathogens.

3.2.3. Environmental hygiene and equipment deficiencies

Several environmental issues were identified, including rusted and unclean equipment such as oxygen cylinders, refrigerator bases, leg poles for OR tables, medication

trolleys, and dialysis cabinets. Additionally, lapses in terminal cleaning were observed, whereby items such as oxygen and suction bottles were left behind after patient discharge or transfer from isolation, and precaution posters were not removed in a timely manner.

3.2.4. Lapses in reprocessing and sterilization protocols

Critical breaches were identified in the chain of responsibility for medical device reprocessing, beginning with clinical areas sending contaminated items to the Central Sterile Supply Department (CSSD) (Table 2). Used dressing sets contained unsheathed sharps, suction bottles were submitted full of secretions, and oxygen bottles arrived with old labels still adhered, practices which exposed CSSD staff to unnecessary risk and compromised the cleaning process. Furthermore, a key finding was the inconsistent handling of bougie catheters, which were primarily being used for endotracheal intubation and occasionally for tracheostomy procedures to facilitate airway management, across units; while the OR, ICU, and high dependency unit sent them to CSSD for reprocessing, the CCU treated them as single-use, chargeable items, a lack of standardization that poses clear infection prevention and patient safety risks. Additionally, post-cleaning aesthetic issues were noted; oxygen bottles, though disinfected, retained residual adhesive from old labels, making them appear dirty and undermining staff confidence in the sterilization process.

3.3. Detailed analysis of high-risk areas and practices

The surveillance data enabled a granular analysis of specific high-risk areas and practices that disproportionately contributed to the risk environment. The OR complex emerged as a critical hotspot (Figure 2). Beyond isolated PPE breaches, systemic issues were documented, such as anesthesia machines having soda lime canisters changed at irregular intervals based on variable color-change interpretations rather than a fixed protocol; unsterilized anesthesia tubing and resuscitation bags were noted to be only externally cleaned; and critical hand hygiene stations were poorly accessible, with hand sanitizer placed under crash trolleys.

The dialysis service, particularly within the CCU, presented a unique and persistent engineering control failure. To accommodate multiple simultaneous dialysis sessions, technicians routinely used long, improvised extension tubing that traversed floor pathways, creating tripping hazards and complicating cleaning protocols.

The CSSD was identified not as a source of failure, but as a recipient of hazardous practices from clinical areas. The surveillance revealed a failure at the first step, as clinical wards consistently sent contaminated items to the CSSD in an unsafe manner (Table 2). This included dressing sets harboring uncapped sharps, posing a severe risk of needlestick injury, and suction bottles containing

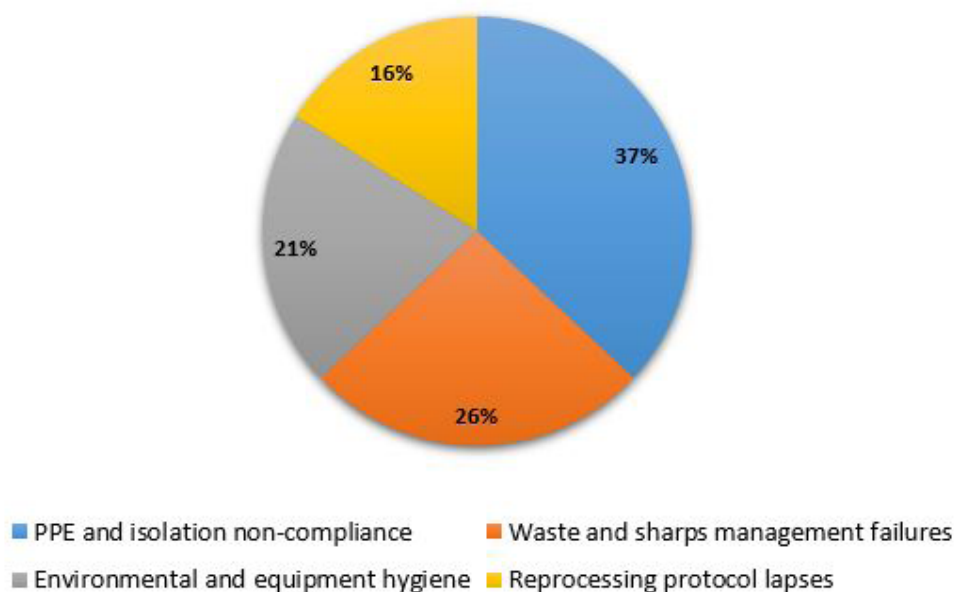


Figure 1. Distribution of major IPC breach categories identified during surveillance. Percentages are based on the total number of breaches identified ($n = 126$).

Abbreviations: IPC: Infection prevention and control; PPE: Personal protective equipment.

Table 2. Selected examples of critical IPC lapses and immediate interventions

Date	Unit	Observation	Immediate corrective action
December 2, 2025	GWD	Staff mobilized a contact-precautions patient without a gown/mask.	Teaching on mandatory full PPE for contact precautions.
December 2, 2025	CCU	Staff did not doff the gown after leaving the isolation room; sharps in the green bin.	Teaching on proper PPE doffing sequence and waste segregation.
December 4, 2025	OR	Anesthetist wearing jewelry during procedure; no gown for intubation.	Reinforced OR dress code and aseptic technique.
Multiple	All	Urine and drainage bags placed on the floor.	Teaching on care bundle-based approach and infection risk from floor contamination.
December 11, 2025	ER	All danger boxes (sharps containers) without labels.	Teaching on labeling protocols for hazardous waste.
December 22, 2025	CSSD	Receiving sets with sharps inside; bottles with secretions.	Teaching clinical staff on pre-cleaning before sending equipment to CSSD.
December 29, 2025	CCU	TB-positive patient in CCU with no airborne precaution poster on door.	Poster placed immediately; staff educated on airborne precautions.

Abbreviations: CCU: Coronary care unit; CSSD: Central Sterile Supply Department; ER: Emergency room; GWD: General ward; IPC: Infection prevention and control; OR: Operating room; PPE: Personal protective equipment; TB: Tuberculosis.

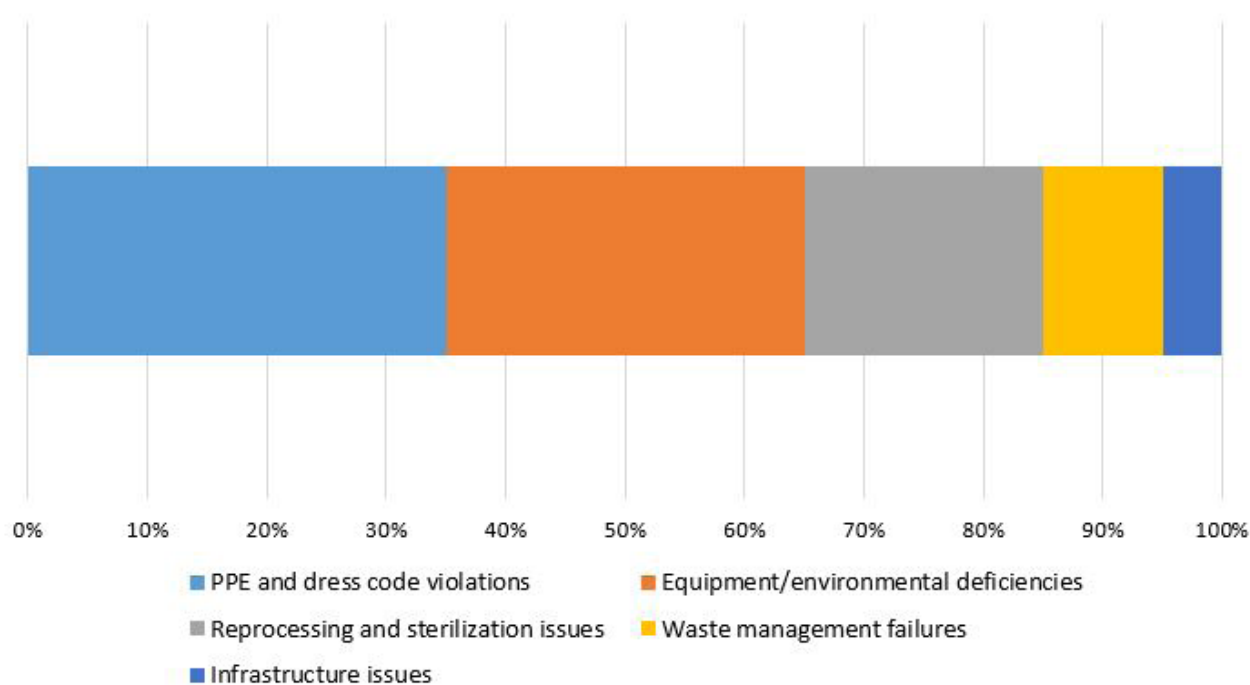


Figure 2. Operating room-related observations and percentages ($n = 27$)
Abbreviation: PPE: Personal protective equipment.

unemptied secretions, which could aerosolize pathogens during handling. This finding reframed the problem from a CSSD processing failure to a critical breakdown in ward-level pre-transport protocols.

3.4. Outcomes of escalation and systemic interventions

While spot teaching addressed individual behavior, escalating systemic issues to unit managers and department heads triggered several concrete administrative actions.

Following the reporting of rusted equipment such as OR tables, oxygen cylinders and dialysis cabinets and dilapidated furniture such as torn OR chairs, formal work orders were issued to the engineering and procurement departments for repair or replacement. Furthermore, the identification of inconsistent bougie catheter reprocessing practices prompted an official interdisciplinary review among the IPC, cardiology, anesthesia, and finance departments to mandate a hospital-wide classification (single-use versus reusable) and standardize the associated protocols and charging practices.

The intensive surveillance and intervention period from December 1–31, 2025 was successful in its primary objective. Following the implementation of enhanced evening shift monitoring, immediate spot corrections, and management escalation of systemic issues, no new cases of CRAB infection have been identified in the ICU or CCU during the post-intervention surveillance period through March 31, 2026 (Figure 3).

4. Discussion

The CRAB outbreak at a tertiary cardiac care center and the subsequent intensive surveillance illuminated a common yet critical scenario in hospital epidemiology, namely the gap between established IPC policies and frontline practice. Our investigation's negative environmental and pharmaceutical cultures strongly pointed to human factors and behavioral non-compliance as the outbreak's primary

driver, a finding consistent with other outbreak reports where lapses in basic infection control measures fueled MDRO transmission.^{4,33} The IPC surveillance in December 2025 served as a diagnostic probe, vividly mapping this gap and demonstrating the efficacy of targeted, real-time intervention.

The decision to focus surveillance on the evening shift proved prescient. The volume and nature of documented breaches, from fundamental PPE errors in isolation rooms to hazardous sharps disposal, suggest that IPC vigilance wanes outside peak administrative hours. This aligns with studies showing that hand hygiene compliance, for instance, is often lower at night and on weekends.^{12,34} The deployment of a senior ICN during this window provided a supervisory presence that is often missing, enabling immediate correction and reinforcing accountability.

The recurring themes of non-compliance are particularly instructive. The persistent misuse of PPE and delays in initiating isolation underscore a failure to apply transmission-based precautions, a cornerstone of MDRO containment. These were compliance rather than knowledge deficits, as spot teaching consistently addressed known protocols. This suggests challenges related to workload, entrenched habits, or a culture that tolerates deviations from protocol, particularly during periods of high operational demand. The environmental and equipment findings, particularly rust and residual contaminants, highlight systemic issues in which

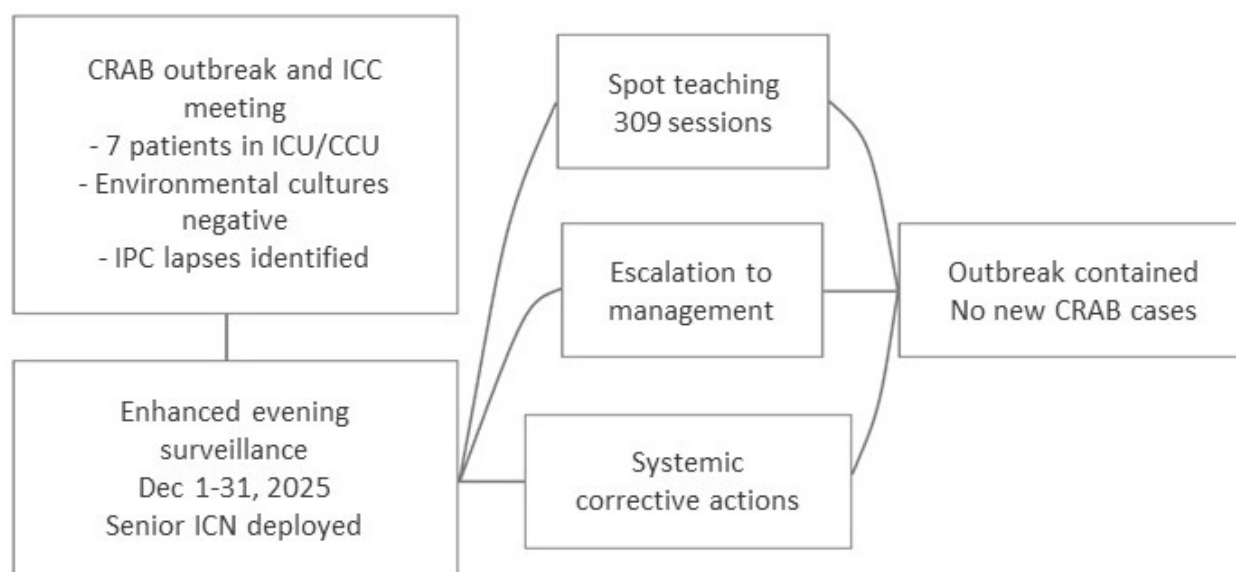


Figure 3. Schematic overview of the multimodal intervention strategy implemented to contain the outbreak

Abbreviations: CCU: Coronary care unit; CRAB: Carbapenem-resistant *Acinetobacter baumannii*; ICC: Infection Control Committee; ICN: Infection control nurse; ICU: Intensive care unit; IPC: Infection prevention and control.

procurement, maintenance, and housekeeping protocols failed to support the IPC infrastructure.

The most concerning findings involved breaches in the sterile processing chain, notably the serious safety hazard of sending sharps-laden sets to the CSSD. The inconsistent classification of bougie catheters (reusable versus single-use) between CCU and other units reveals a critical lack of standardization, which can lead to both infection risks from inadequate reprocessing and unnecessary costs due to premature disposal. Therefore, implementing standardized, hospital-wide protocols for medical device classification and reprocessing is essential to prevent such breaches.

Although the 309 spot teaching sessions proved instrumental in promptly correcting breaches, their primary value resides in their diagnostic utility rather than serving as a perpetual solution. The recurring pattern of similar lapses over multiple weeks, including urine bags placed on floors or the absence of isolation signage, underscores a “see-one, correct-one” cycle that fails to foster sustained behavioral change. This exemplifies the perennial challenge in healthcare quality improvement, namely transitioning from initial gains to enduring, embedded practices.⁷ Spot teaching excels at heightening awareness and delivering just-in-time knowledge, yet it carries the risk of fostering dependency on an external “IPC police” force.^{18,35} Achieving long-term success demands internalizing these practices into professional habits and unit culture. Complementary strategies are essential, including peer-to-peer accountability frameworks, the incorporation of IPC metrics into individual and unit performance evaluations, and empowering charge nurses and team leaders to uphold IPC compliance across every shift rather than solely during surveillance rounds. Moreover, the diminishing efficacy of spot teaching for repeat offenders suggests that entrenched behaviors may require formal performance-management interventions alongside educational efforts.

The primary reasons for the observed non-compliance with standard operating procedures were multifaceted. A key contributing factor was the reduced supervisory oversight during evening and night shifts, a period characterized by lower staff-to-patient ratios, increased workload, and reduced administrative presence, which collectively created an environment in which deviations from established protocols could go undetected or uncorrected. This finding is consistent with previous studies demonstrating diurnal variation in IPC compliance, particularly hand hygiene and PPE adherence, which tend to decline during off-peak hours when direct observation is less frequent.^{12,13} Additionally, systemic barriers, including poor accessibility of hand sanitizers,

shortages of appropriately sized PPE, and confusing waste segregation guidelines, contributed to inadvertent non-compliance. The “know-do gap,” where healthcare workers possess theoretical knowledge of protocols but fail to translate it into consistent practice, was also evident, often due to cognitive overload in high-acuity settings, time pressure, and habitual shortcuts that became normalized over time.^{15,17} Notably, the recurrence of similar breaches across multiple weeks and different staff members suggests that these were not isolated individual errors but rather systemic and cultural issues that required institutional-level solutions beyond individual education.^{10,11}

In response to the identified gaps, a targeted training program, the “Infection Prevention and Biosafety Assessment Initiative” (IPBAI), was implemented as a complementary strategy to the spot teaching conducted during the surveillance period. This initiative consisted of comprehensive refresher training sessions delivered by the infection control team to all clinical and non-clinical staff across the institute. The training covered the ten core pillars of infection prevention and control, namely, hand hygiene, PPE use, sharps handling, standard and transmission-based precautions, environmental cleaning, spill response, respiratory hygiene, needlestick injury response, antimicrobial stewardship, and care bundle-based approaches. Sessions were conducted for physicians, nurses, pharmacists, allied health professionals, housekeeping staff, laboratory personnel, and security staff to ensure institution-wide awareness and competency. The training used a multimodal approach, including didactic lectures, practical demonstrations, case-based discussions, and competency assessments, to reinforce correct practices and address the specific breaches identified during surveillance.

Beyond the initial training, a sustainability framework was established to ensure ongoing competency and accountability. The institute already maintains a schedule of mandatory annual refresher training for all staff, but the IPBAI initiative represented an intensified, targeted intervention in response to the outbreak. Additionally, the existing system of daily IPC rounds by ICNs continues, with more frequent audits during evening and night shifts. The institute’s infection control monitors, designated staff members in each department who serve as IPC liaisons, continue to conduct routine observations and report any breaches or concerns to the IPC team for timely corrective action. This infrastructure ensures that training is not a one-time event but part of a continuous quality improvement cycle, with ongoing monitoring, feedback, and re-education to maintain high standards of IPC practice across all shifts and departments. Our institute

already operates a robust monitoring infrastructure in which ICNs conduct daily unannounced rounds across all clinical and support areas, systematically observing IPC practices and documenting compliance with standardized checklists. These rounds are supplemented by scheduled audits targeting specific areas, including hand hygiene, PPE use, environmental cleaning, and device reprocessing. Additionally, each clinical department has designated infection control monitors, trained staff members, responsible for conducting routine observations within their units and reporting any breaches or concerns directly to the IPC team. This distributed monitoring system, combined with the enhanced evening-shift surveillance described in this study, provides comprehensive coverage across all shifts and categories of IPC non-compliance.

The surveillance presented in this study clearly demonstrated that frontline IPC compliance is frequently constrained or facilitated by systemic and administrative decisions. Factors such as rusted equipment, insufficient waste-bin supplies resulting in overfilling, and the absence of dialysis extension ports reflected deficiencies in maintenance, procurement, and facility planning rather than shortcomings of clinical staff. A fundamental principle of resilient healthcare systems is that they must be designed to make adherence to optimal practices the default and simplest choice. Consequently, outbreak responses must transcend the IPC department to encompass hospital administration, engineering, and finance directorates. Investments in seamless, easy-to-clean equipment, reliable supplies of suitable consumables such as appropriately sized waste bags, and workflows intentionally designed with IPC principles are indispensable elements of patient safety infrastructure, not discretionary expenditures.

The achievements of this intensive one-month initiative should reshape institutional perceptions of IPC surveillance. Far from a mere routine or punitive audit, it ought to be recognized as a continuous, proactive sentinel mechanism for patient safety. The CRAB outbreak served as a sentinel event, revealing entrenched vulnerabilities. The December surveillance program illustrated that a more frequent, rigorous, and shift-spanning approach can detect and avert risks before they escalate into full outbreaks. This approach resonates with the paradigm of preemptive or proactive infection control, which leverages process compliance data not merely for infection enumeration but for prediction and prevention.^{31,36} Henceforth, the IPC department's remit should be strengthened to include routine deep-dive surveillance in high-risk areas across all shifts, complemented by the authority to implement rapid-cycle improvements. The resultant data on breach types and frequencies should be disseminated not as evaluative

report cards but as strategic dashboards to inform hospital leadership's resource allocation and policy prioritization, thereby elevating IPC from a siloed departmental function to a core organizational imperative.

The study has a few limitations that should be considered when interpreting the findings and their generalizability. First, this was a single-center, prospective quality-improvement investigation conducted over a short one-month intervention period, which limits external validity and does not allow assessment of the long-term sustainability of the observed effects. Second, the observational design did not include a concurrent control group or robust baseline quantitative compliance indicators such as continuous blinded hand hygiene audits or denominator-based compliance rates, making it difficult to establish a direct causal relationship between the intervention and outbreak control and leaving room for potential confounding by parallel administrative and system-level actions. Third, several sources of bias may have influenced the results, including the Hawthorne effect and observer or recording bias, as visible unannounced rounds and real-time documentation may have altered staff behavior and preferentially captured easily observable practices while overlooking less visible non-compliance. Fourth, microbiological and molecular epidemiological analyses were limited, as environmental and pharmaceutical cultures were negative and no molecular typing or whole-genome sequencing was performed, preventing definitive confirmation of transmission pathways and genetic relatedness between isolates. Fifth, the outbreak involved a small number of affected patients, and key patient-centered outcomes, such as attributable mortality, length of hospital stay, and cost implications, were not systematically evaluated, limiting conclusions about clinical impact and cost-effectiveness. Additional limitations include variability in the definition and intensity of spot-teaching activities, which may have introduced heterogeneity in exposure; the resource-intensive nature of the intervention, which may limit scalability in low-resource settings; and the lack of objective assessment of sustained behavioral change after the surveillance period ended. Collectively, these limitations underscore the need for larger, multicenter studies with longer follow-up periods, standardized quantitative infection prevention metrics, incorporation of molecular epidemiology, formal evaluation of clinical and economic outcomes, and the inclusion of appropriate comparison groups to better define effectiveness and reproducibility.

5. Conclusion

The successful containment of the CRAB outbreak at a cardiac tertiary care center was achieved through a targeted

multimodal strategy rather than a single intervention, addressing underlying systemic and behavioral gaps in IPC compliance. Deployment of senior IPC expertise during the high-risk evening shift was critical, enabling the identification of latent hazards not detected during routine daytime surveillance. The spot-teaching approach further facilitated timely corrective feedback and immediate improvements in practice.

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Conflict of interest

The authors declare that they have no competing interests.

Author contributions

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Ethics approval and consent to participate

Ethical approval was not required for this outbreak investigation because it constituted routine public health surveillance conducted by the institutional Department of Infection Control for immediate outbreak response and infection prevention purposes. Accordingly, individual informed consent to participate was not required. The investigation was conducted in accordance with institutional policies and standard infection prevention and outbreak management protocols, and all patient data were handled confidentially.

Consent for publication

Written informed consent for publication was not obtained from individual patients, as this investigation was a public health surveillance activity conducted for immediate outbreak control and infection prevention. All data presented have been rigorously de-identified and aggregated to ensure complete patient anonymity, with no personal identifiers, protected health information, or identifiable clinical details included in the manuscript. This approach is in accordance with established ethical guidelines for public health practice and outbreak reporting, in which the imperative to disseminate findings promptly to protect public health outweighs the requirement for individual consent, provided confidentiality is strictly maintained. The investigation was conducted under the authority of the institutional Department of Infection Control and in accordance with internal protocols for outbreak management and data reporting.

Availability of data

All data generated during the course of this project are included in the published article.

Further disclosure

An earlier version of this work was made publicly available as a preprint on Research Square (doi: 10.21203/rs.3.rs-8747601/v1).

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